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PREFACE

This publication is a compilation of summaries of reports written by Principal Investigators funded through the Planetary Astronomy Program of NASA's Solar System Exploration Division, Office of Space Science and Applications.

The summaries are designed to provide information about current scientific research projects conducted in the Planetary Astronomy Program and to facilitate communication and coordination among concerned scientists and interested non-scientists in universities, government, and industry.

The reports are published as they were submitted by the Principal Investigators and have not been edited. They are arranged in alphabetical order.

Jurgen H. Rahe
Discipline Scientist
Planetary Astronomy Program
Solar System Exploration Division

July 1987

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

OBSERVATIONS OF COMETS AND ASTEROIDS

PERFORMING ORGANIZATION

Astronomy Program, Department of Physics and Astronomy
University of Maryland, College Park, MD 20742-4111

INVESTIGATOR'S NAME

Michael F. A'Hearn

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Strategy - observe small bodies of solar system to (ultimately) understand origin and evolution of solar system.

b) Progress past year - i) Initiated processing of narrow-band CCD images of Halley. Progress slow due to start-up phase of image processing at Maryland. ii) Showed that CN and C_2 both occur in long-lived jets, argued this is due to dissociation from surface of grains, presumably CHON particles observed from spacecraft. iii) Showed that jets correlated with variability seen in C_2 and CN photometry and in HCN radio data, i.e. jets absent at times of minima. iv) showed that ions exhibit a strong, diffuse component underlying the rays and that H_2O^+/CO^+ ratio varies considerably from ray to ray. v) Completed and published analyses of previous optical/IR data on Comets P/Neujmin 1 and P/Arend-Rigaux showing their nuclei are big and black (preliminary results previously published). vi) Published results of Ceres occultation showing it is smaller than most measures except that from IR Radiometry. vii) Carried out CCD observations of Comet Wilson to study ions, of Comet Halley to study rotational variations, and a search for P/Oterma. ix) Began modelling temporal variabilty to determine parent lifetimes.

c) Plan for next year - i) Reduction and analysis of CCD images of Halley to determine - nature of neutral radical jets, nature of variability, source-region and mechanism ionization. ii) Preliminary reduction of images of Wilson. iii) Modelling of variability as measured by photometers/spectrophotometers (IHW data, IUE data) to learn lifetimes of parent molecules. iv) Further observations with CCD of P/Halley and P/Tempel 2.

Bibliography (1986-87) of work supported by this grant:

A'Hearn, M.F., Hoban, S., Birch, P.V., Bowers, C., Martin, R. and Klinglesmith, D.A., 1986, Cyanogen Jets of Halley, **Nature**, **324**, 649-651.

Campins. H., A'Hearn, M.F., and McFadden, L.A., 1987, The Bare Nucleus of Comet Neujmin 1, **Ap.J. 316**, 847-857.

Millis, R.L., A'Hearn, M.F. and Campins, H., 1987, The Coma and Nucleus of Comet Arend-Rigaux, submitted to **Ap.J.**

Millis, R.L.,...A'Hearn, M.F. ...(total of 40 authors), The Size, Shape, Density and Albedo, of Ceres from its Occultation of BD+8°471, 1987, **Astron. J.** (in press)

Hoban, S., Samarsinha, N.H., A'Hearn, M.F. and Klinglesmith, D.A., 1987, The Nuclear Rotation Period of Comet P/Halley as Determined by an Analysis of the Morphology of CN Jets, submitted to **Astron. & Ap.**.

A'Hearn, M.F., Hoban, S., Birch, P.F., Bowers, C., Martin, R., and Klinglesmith, D.A. 1986, Gaseous Jets in Halley, in Proceedings of ESLAB symposium on the Exploration of Halley's Comet, **ESA SP-250**, 483-486

Samarasinha, N.A., A'Hearn, M.F., Hoban, S., and Klinglesmiwth, D.A., 1986, CN Jets of Comet P/Halley - Rotational Properties, in Proceedings ESLAB symposium on the Exploration of Halley's Comet, Heidelberg, **ESA SP-250**, 487-491.

Hoban, S., A'Hearn, M.F., Birch, P.V., Candy, M.P., Martin, R., and Klinglesmith, D.A., 1986, Ion Morphology in the Inner Tail of Comet P/Halley, in Proceedings ESLAB symposium on the Exploration of Halley's Comet, Heidelberg, **ESA SP-250**, 505-506.

Schleicher, D.G., Millis, R.L., Tholen, D., Lark, N., Birch, P.V., Martin, R., and A'Hearn, M.F., 1986, The Variability of Halley's Comet during the Vega, Planet-A, and Giotto Encounters, in Proceedings ESLAB symposium, on the Exploration of Halley's Comet, Heidelberg, **ESA SP-250**, 565-567.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Theoretical Spectroscopy of Comets

PERFORMING ORGANIZATION

Astronomy Program, Department of Physics and Astronomy
University of Maryland, College Park, MD 20742-4111

INVESTIGATOR'S NAME

Michael F. A'Hearn

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Strategy - Calculate theoretical spectra of cometary species both to interpret observed spectra thereby learning about physical conditions in comae and to provide fluorescence efficiencies for the derivation of abundances.

b) Progress and Accomplishments

i) New start this year. ii) Spectrum of SO is not consistent with proposed identifications for Krishna-Swamy and Wallis. Upper limits on abundance of SO are too high to be interesting. Awaiting better data. iii) spectrum of NH requires no collisional effects, i.e. NH must be far from nucleus contrary to masured scale lengths. Fluorescence efficiencies factor of 5 lower than previously published. Paper in preparation. iv) Preliminary work on OD and ^{18}OH suggests interesting results in data from IUE

c) Proposed Tasks this Year

i) Publish NH results. ii) Complete analysis of OD and of ^{18}OH. iii) Calculate spectrum of CN^+ for comparison with data from IUE.

d) No publications yet.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
Planetary Research at Lowell Observatory
NGR-03-003-001

PERFORMING ORGANIZATION
Lowell Observatory
Mars Hill Road
Flagstaff, AZ 86001

INVESTIGATOR'S NAME
William A. Baum
602-774-3358

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Present research under this grant is focused on comets, asteroids, Pluto, Charon, and Triton. The comet studies are aimed at a better determination of the basic physical characteristics of cometary nuclei, a more complete understanding of the complex processes in the comae, a survey of abundances and gas/dust ratios in a large number of comets, and a measurement of primordial $^{12}C/^{13}C$ and $^{14}N/^{15}N$ ratios. Other studies concern more precise dimensions of Pluto and Charon, an improved determination of the mass of Triton, and a search for Chiron-like bodies beyond the main asteroid belt. In general, this research is in support of existing or planned missions.

(b) Reduction and preliminary analysis of narrowband photometric observations of Comet P/Halley from 74 nights in 1985 and 1986 were completed. A detailed record of Halley's activity throughout a 6.5-week interval spanning the various spacecraft encounters was produced, revealing a 7.4-day period in the comet's production of gas and dust. A photometric study of P/Giacobini-Zinner was completed, which showed a pronounced depletion of C_2 and C_3 and an extreme asymmetry in activity around perihelion. A determination of the dimensions, albedo, and rotation period of the nucleus of P/Arend-Rigaux was finished. Continuum luminosity profiles of 18 comets were re-derived from CCD observations and modeled in terms of radial outflow, radiation pressure, and grain evolution. C_2 profiles of three comets yielded scale lengths differing substantially from canonical values. High-resolution spectra of P/Halley were recorded in the regions of CN bands, C_2 fluorescence emission, and [OI] lines. Two Pluto-Charon mutual events were observed.

(c) The large body of photometric data on P/Halley will be analyzed to define the comet's short-period variation more completely, to derive lifetimes and outflow velocities of observed gases, and to characterize Halley's photometric behavior throughout the apparition. Our existing photometric database for about 60 comets will be re-reduced on a standard system to delineate diversities and similarities more clearly. New observations will include P/Encke, P/Borrelly, and P/Tempel 2. The analysis and interpretation of existing CCD luminosity profiles will be completed. Analyses of high resolution spectra of P/Halley will be extended. Several Pluto-Charon events will be observed, and CCD images of Neptune will be obtained to seek its barycentric motion and thereby determine Triton's mass. Existing pairs of UCAS Schmidt plates will be blinked in search of small bodies beyond the asteroid belt. In August (1987) we are hosting an international workshop on *Time-Variable Phenomena in the Jovian System*, in which about 150 planetary scientists will participate.

d) Bibliography (papers published or in press during the past six months, excluding abstracts)

Baum, W. A., and Kreidl, T. J. (1986). Volatiles in cometary grains. In *Asteroids, Comets, and Meteors, II.* (C. -I. Lagerkvist, B. A. Lindblad, H. Lundstedt, and H. Rickman, eds.), pp. 397–402. Uppsala University, Uppsala.

Millis, R. L., and Schleicher, D. G. (1986). The rotational period of Comet Halley. *Nature* 324, 646–649.

Millis, R. L., A'Hearn, M. F., and Campins, H. (1987). An investigation of the nucleus and coma of Comet P/Arend-Rigaux. Submitted to *Astrophys. J.*

Schleicher, D. G., *et al.* (1986). Comets P/Giacobini-Zinner and P/Halley at high dispersion. In *New Insights in Astrophysics - 8 Years of UV Astronomy with IUE.* ESA SP-263, 31-33.

Schleicher, D. G., Millis, R. L., Tholen, D., Lark, N., Birch, P. V., Martin, R., and A'Hearn, M. F. (1986). The variability of Halley's Comet during the Vega, Planet-A, and Giotto encounters. In *20th ESLAB Symposium on the Exploration of Halley's Comet.* ESA SP-250, Vol. 1, 565-567.

Schleicher, D. G., Millis, R. L., and Birch, P. V. (1987). Photometric observations of Comet P/Giacobini-Zinner. *Astron. Astrophys.*, in press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Long-Term Changes in Reflectivity and Larger Scale Motions in the Atmospheres of Jupiter and Saturn

PERFORMING ORGANIZATION

New Mexico State University
P. O. Box 4500
Las Cruces, New Mexico 88003

INVESTIGATOR'S NAME

R. F. Beebe

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) A 61 cm. reflecting telescope, with f75 or f40 optics, equipped with a focal-plane camera is committed to an on-going monitoring program. Multi-color imaging, utilizing broad-band filters is systematically carried out. Using 3.25 X 4.25 inch Kodak glass plates, geometric and relative photometric calibration are included on each plate, resulting in a low-cost archive that has been maintained since 1968; hence, a continuous record for interpreting Pioneer and Voyager images and planning for the Galileo Mission is being maintained. Positional measurements of long-lived cloud systems, such as the Red Spot and White Ovals, and long-term variability of the belt-zone reflectivity are monitored. Evidence for the onset of sporadic convective events and recurrence of cloud systems that are typical of specific latitudinal regions are noted and integrated into the historical data set.

(b) The 1986-87 data set has been acquired, rated, catalogued and archived. Positional measurements of long-lived cloud systems have been obtained, using a Mann projection system. Analysis indicates that the Red Spot has drifted at a nearly constant velocity since 1937 or for the life-time of the present White Ovals. A paper concerning the non-linear drift rates of these long-lived features is nearing completion. Analysis of the Red Spot, spanning the time interval from 1968 to 1984, indicated a possible seasonal dependence in the residual of the longitudinal positions versus time. Addition of the 1985 and 1986 data modifies the trend somewhat. Although the seasonal dependence of the velocity is still indicated, a deceleration term must be included in the analysis.

(c) A continuation of this project is planned. This research provides a low-resolution, time-dependent framework, within which the short-term high resolution space-craft data sets can be interpreted.

(d) Beebe, R.F. and T.A. Hockey: A Comparison of Red Spots in the Atmosphere of Jupiter, Icarus, 67,96,1986.

Beebe, R.F., R.M. Suggs and T. Little: Seasonal North-South Asymmetry in the Solar Radiation Incident of Jupiter's Atmosphere, Icarus, 66, 359,1986.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Spectral Studies of Asteroids

PERFORMING ORGANIZATION

Planetary Geosciences Division
Hawaii Institute of Geophysics
2525 Correa Road / Honolulu, HI 96822

INVESTIGATOR'S NAME

Jeffrey F. Bell (808)-948-6488

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) *Strategy:* The research objective is to improve our understanding of the surface mineralogy of asteroids and to link the vast existing body of meteorite geochemical data with specific astronomical objects which may be the targets of future NASA missions. The methodology employed is 1) use advanced astronomical instrumentation to obtain reflection spectra in the 0.3-5.2μm wavelength range of selected asteroids; 2) compare the asteroid data with similar data on simulated asteroid regoliths of various compositions to determine the surface mineralogy and meteoritic affinities of asteroid spectral classes and specific asteroids; 3) intergrate the mineralogical information with other astronomical data, orbital dynamics studies, and meterorite geochemistry data to reconstruct the condensational, thermal, and collisional history of the present asteroids and their parent planetesimals; 4) use the information obtained to asist planning of future NASA asteroid missions such as Galileo and CRAF.

b) *Progress* (1986-87): Completed 0.8-2.5μm spectral survey of Tholen's taxonomic types; began comprehensive survey of S-type asteroids; began observing selected members of Flora, Eos, and Koronis asteroid dynamical families; provided information for selection of candidate asteroid flyby targets for Galileo and CRAF missions; searched for 0.9μm pyroxene absorption band in Mercury.

c) *Proposed Research:* Complete and publish backlog of manuscripts in preparation; continue to aquire spectra of selected S-type asteroids and members of asteroid dynamical families; continue attempts to confirm existence of 0.9μm absorption band in Mercury; continue to assist planning for Galileo and CRAF mission asteroid flybys.

d) *Summary Bibliography* (1986-87): 2 papers, 3 extended abstracts, 2 papers submitted.

e) *Manpower:* 1 faculty (3 man-months), 1 research technician (2 woman-months)

Bell, J. F., "Asteroid Dynamical Families: Mostly Mythical?" In *Lunar and Planet. Sci. XVII,* 983, 1986.

Bell, J. F., "Mineralogical Evolution of Meteorite Parent Bodies." In *Lunar and Planet. Sci.* **XVII,** 985, 1986.

Bell, J. F., "Mineralogical Evolution of the Asteroid Belt." *Meteoritics* **21,** 333, 1986.

Bell, J. F., and B. R. Hawke, "Recent Comet Impacts on The Moon: The Evidence from Remote Sensing Studies." *Pub. Ast. Soc. Pacific,* to appear August 1987.

Bell, J. F., "Mineralogical Variety of the Asteroid Belt," *Proceedings of the Multiple Comet Mission Workshop,* Goddard Space Flight Center, in press 1987.

Piscitelli, J. R., D. P. Cruikshank, and J. F. Bell, "Laboratory Studies of Irradiated Nitrogen-Methane Mixtures: Applications to Triton." *Icarus,* submitted March 1987.

Bell, J. F., R. H. Brown, and B. R. Hawke, "Composition and Size of Earth-Crossing Asteroid 1984KB." *Icarus,* submitted May 1987.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Spectroscopy

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

J. T. Bergstralh, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. The goal of this task is to acquire spectroscopic and spectrophotometric data on the atmospheres of comets, the outer planets, and Titan at ultraviolet to near-infrared wavelengths (approx. 0.2-2.5 μm). These data support an effort aimed at characterizing the physical properties and distribution of aerosol particles in the atmospheres of these bodies. This task supports only data acquisition and reduction; modeling is performed under task 154-30-80-10-55.

b. Wrote invited review paper on scientific investigations of Uranus, 1983-1986, as part of U.S. National Report to IUGG. Acquired new spectrophotometry of Uranus and Neptune at $0.2 < \lambda < 0.3$ μm with IUE; acquired and recalibrated archival IUE spectrophotometry of Uranus and Neptune in this wavelength range. Paper reporting this work submitted to Icarus. Acquired new high-resolution spectra of H_2 (3-0) and (4-0) quadrupole lines in Uranus and Neptune, using pressure-scanned Fabry-Perot spectrometer at coude of Palomar 5-meter telescope (collaboration with J. T. Trauger, JPL). McDonald Observatory observation run washed out by rain.

c. Objectives for FY'88 includes: (1) organize, conduct, and edit proceedings of Uranus symposium (collaboration with M. Matthews, Univ. of Arizona), (2) spectrophotometry of Uranus and Neptune with HST High Resolution Spectrograph, if launched, to acquire quantitative data on Raman scattering by molecular hydrogen.

d. Two refereed journal articles (Icarus, Rev. Geophys.); three abstracts (DPS--B.A.A.S.).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

PHOTOMETRY OF PLUTO-CHARON MUTUAL EVENTS AND HIRAYAMA FAMILY ASTEROIDS

PERFORMING ORGANIZATION

Planetary Science Institute
2030 E. Speedway
Tucson, AZ 85719

INVESTIGATOR'S NAME

Richard P. Binzel

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Once every 124 years, nature provides earth-bound astronomers the opportunity to observe occultation and transit phenomena between Pluto and its satellite, Charon. Ground-based observations of these events will allow precise physical parameters for the Pluto-Charon system to be derived which are unlikely to be improved upon until *in situ* spacecraft observations are obtained in the distant future. The proposed three year program will support observations from McDonald Observatory, a critical location in the International Pluto Campaign network. Knowledge of the diameters, masses, densities, and compositions derived from these observations will augment our understanding of Pluto's origin and its context within the problem of solar system formation.

A second task will continue my investigation (Binzel 1986) into the processes of catastrophic disruption and collisional evolution in the asteroid belt through physical observations of Hirayama family members, which are remnants of distinct catastrophic collisions. Observations of Koronis, Eos, Themis, and Nysa family members obtained during the proposed three year program will be compared with laboratory and numerical collision models to obtain a better understanding of collision processes and therefore better determine how the asteroid belt has evolved over the age of the solar system. Knowledge of the initial state of these planetesimals can provide insights to the processes of planetary accretion and solar system formation.

(b) NEW PROPOSAL

(c) This year, high time resolution and high precision photometry observations will be obtained for four to six Pluto-Charon mutual events using the McDonald Observatory 2.1- and 2.7-m telescopes. Events observed in 1987 and 1988 will involve total transits and occultations which are especially critical events for deriving physical parameters. The McDonald data will be combined with observations at other longitudes to allow the best possible solution to be derived for diameters, masses, and densities in the Pluto-Charon system. Continued observations in the second and third years will allow these values to be determined more precisely and will also allow an albedo surface map to be constructed for one hemisphere of each body.

Observations of approximately 20 Hirayama family asteroids will be obtained this year utilizing about 20 nights of 1-m telescope time at McDonald and Kitt Peak observatories. Lightcurve observations of Koronis family asteroids at ecliptic longitudes ~90 degrees away from previous measurements will be used to test whether this family has a preferential low obliquity alignment, which is evidence for a recent formation. Observations of Themis, Nysa, and Eos family members in all three years will broaden our understanding of asteroid collisional evolution.

(d) Mulholland, J. D. and Binzel, R. P. (1984). "Eclipse Phenomena in the Pluto-Charon System." *Astron. J.* 89, 882-888.

Binzel, R. P., Tholen, D. J., Tedesco, E. F., Buratti, B., and Nelson, R. (1985). "The Detection of Eclipses in the Pluto-Charon System." *Science* 228, 1193-1195.

Binzel, R. P. (1986). *Collisional Evolution in the Asteroid Belt: An Observational and Numerical Study*. Ph. D. Thesis, University of Texas at Austin.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Studies of Asteroids, Comets, and Jupiter's Outer Satellites

PERFORMING ORGANIZATION

Lowell Observatory

INVESTIGATOR'S NAME

Edward Bowell

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Our work comprises observational, theoretical, and computational research on asteroids, together with a smaller effort concerning the astrometry of comets and Jupiter's outer satellites JVII through JXIII. Two principal areas of research, centering on astrometry and photometry, are interrelated in their aim to study the overall structure of the asteroid belt and the physical and orbital properties of individual objects.

(b) We have measured and published about 2500 accurate photographic positions of asteroids and comets. CCD astrometry of about 50 targets has led to the recovery of a number of critical-list asteroids, close-Earth-approachers, and multi-apparition unnumbered asteroids. JVII, JVIII, JXI, and JXIII have been observed. We were able to follow up almost all bright asteroids and comets discovered during 1986, thus helping establish good orbits for those bodies. Two comets (P/Skiff–Kosai = 1976XVI and P/Wiseman–Skiff = 1987b) were discovered, and about 40 of our asteroid discoveries were numbered. A paper on very accurate (±0"02?) astrometry of P/Halley, using a stellar appulse technique, is in preparation. Orbit files have been updated monthly, and ephemerides have been distributed to observers on request. A series of CCD lightcurves of Chiron (±0.015 mag rms) enabled us to establish this unusual object's rotation period. Work was continued on the computation of phase curves and lightcurves for various asteroid models, and a papers entitled "Modelling asteroid brightness variations. I. Numerical methods" and "II. On the uninterpretability of phase curves and lightcurves" are near completion. Our investigation into the inversion of asteroid lightcurves has involved understanding the observational requirements and the interpretation of laboratory test data. A paper on a new asteroid magnitude system for IAU Commission 20 is near completion.

(c) Our main astrometric effort will concern startup of a deep, bias-correctable asteroid survey, the aim of which is to derive the true spatial distribution of asteroids down to subkilometer diameters. We plan to follow three fields, each observed about eight times over a two-month interval. It is anticipated that orbits for ~3000 asteroids will result. To accommodate the new survey, our other astrometry programs will proceed at a reduced rate. We plan to observe JVII through JXIII three times each. We will undertake high-precision CCD astrometry of P/Grigg–Skjellerup in support of *Giotto*. Eleven asteroids of interest for the scale calibration of HST will be targeted for CCD lightcurve studies, as will faint targets of opportunity, particularly close-Earth-approachers. The work on lightcurve interpretation will progress through completion of the "uninterpretability" paper; another paper will concern the displacement of an asteroid's photocenter with rotation and phase angle and the modelling of lightcurves of asteroids occulted by the Moon. Our study of asteroid lightcurve inversion will move on to the analysis of "real" lightcurve observations. Further work on the asteroid magnitude system will center on the analysis of a larger asteroid database and parametrization of variations in the opposition effect, particularly the sharp surges seen in the phase curves of some icy satellites.

(d) Summary Bibliography

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Observations of Small Solar-System Bodies

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

R. H. Brown, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) OBJECTIVES--(*TASK 1*): To measure the reflectance spectra of the icy satellites of Jupiter, Saturn, Uranus and Neptune in the region 2.0 to 2.5 μm using the 32-element InSb photodiode array spectrometer of the IRTF at Mauna Kea Observatory. The specific objective is to search for methane, ammonia and carbon monoxide ices and clathrates on icy surfaces in the outer solar system. The data will allow upper limits to be placed on the amount of these chemical species present. Specific targets are Enceladus, Ariel, Titania, and Triton. (*TASK 2*): Analysis of the 0.8- to 2.6-μm reflectance spectra of S-type asteroids to provide a complete characterization of their compositional spectrum and their link to smaller but related taxonomic classifications of asteroids. Spectra have been obtained for about 100 S-type asteroids in the previous 2 grant years and will serve as the data base.

b) PROGRESS: The PI has obtained important new data on Europa and Enceladus. Evidence for the transient presence of a volatile, perhaps $NH_3 \cdot OH$, on Europa has been obtained; this is the first evidence for the presence of NH_2 on any solid surface in the outer solar system. A paper has been submitted to *Icarus*. Newly obtained spectra of Enceladus suggest that it may also have a deposit of volatile ice on its trailing side (the side that has undergone extensive, recent resurfacing). A paper is in preparation for submission to *Icarus*. Observations of Triton showed a marked decrease in the strength of its methane absorptions compared to data obtained in 1980, suggesting large-scale seasonal effects are at work. A paper detailing those results has been submitted to *Icarus*. Spectra of about 100 S-type asteroids have been reduced to relative reflectance and interpretative work has been started. Preliminary analysis suggests that S-type asteroids are differentiated rather than primitive bodies. A paper detailing these results will be submitted near the end of this year.

c) PROPOSED WORK: It is proposed to continue to observe Europa, Enceladus, Ariel and Triton as primary objects as well as obtain new observations of Dione, Rhea and Titania. It is also proposed that the detailed interpretative work on the S-type asterod data continue, with the results to be published near the end of this year.

d) SUMMARY BIBLIOGRAPY:

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

ARECIBO S-BAND RADAR PROGRAM

PERFORMING ORGANIZATION

NATIONAL ASTRONOMY AND IONOSPHERE CENTER
CORNELL UNIVERSITY
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PUERTO RICO 00613

INVESTIGATOR'S NAME

DONALD B. CAMPBELL

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a)General Objectives: The high powered 12.6cm wavelength radar on the 1000 ft Arecibo reflector is utilized for a number of solar system studies. Chief among these are: 1) Surface reflectivity mapping of Venus, Mercury and the Moon. Resolutions achievable on Venus are less than 1.5km over some areas, for Mercury about 30km and for the Moon 200m at present. 2) High time resolution ranging measurements to the surfaces of the terrestrial planets. These measurement are used to obtain height profiles and scattering parameters in the equatorial region. They can also be used to test relativistic and gravitational theories by monitoring the rate of advance of the perihelion of the orbit of Mercury and placing limits on the stability of the gravitational "constant". 3) Measurements of the orbital parameters, figure, spin vector and surface properties of asteroids and comets. 4) Observations of the Galilean Satellites of Jupiter and the satellites of Mars, Phobos and Diemos.

b)Past Twelve Months: Detailed comparisons of the Arecibo Venus radar imagery and altimetry with Pioneer Venus data and the Soviet Venera 15/16 images continued at Brown University and Arecibo. Several papers covering work on Ishtar Terra, Aphrodite Terra and crater properties have been completed. A number of ranging observations were made to Venus and Mercury with the aims described in a). Lunar radar images with resolutions between 200m and 400m were obtained for ten areas. This program is aimed at generating lunar radar images at similar resolutions to those expected for the Magellan Mission to Venus in order to study the influence of incidence angle and aspect angle on their interpretability. Nine asteroids were studied with the radar, seven mainbelt asteroids and two near earth objects. Analysis of the data from 1986DA obtained in April, 1986, indicates that it is the best candidate to date for having a high ion content. Analysis of the radar return from Halley's comet indicates that most of the echo is from small particles in the vicinity of the comet.

The Next Twelve Months: Analysis of the Venus images and comparative studies with the Venera 15/16 data will continue. A number of ranging observations will be made to Venus and Mercury. The lunar program will continue and new equipment available in the fall will allow the resolution to be improved to approximately 50m. The Galilean satellites will be observable in late 1986 for the first time in six years. Intensive observations will be made to refine the current estimates of the radar scattering parameters and to correlate radar features with Voyager images. An attempt will be made to measure polarization ratios and cross sections at 70 cm wavelength. Nine asteroids will be observed including Icarus. Preparations will be made to observe Phobos and Diemos for the first time in late 1987.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Astronomy

PERFORMING ORGANIZATION

Planetary Science Institute
2030 E. Speedway Suite 201
Tucson, AZ 85719

INVESTIGATOR'S NAME

Clark R. Chapman

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. This project supports continued Planetary Astronomy research by five senior scientists at P.S.I. (Drs. Campins, Chapman, Davis, Hartmann, and Weidenschilling), with some involvement also of Dr. Binzel. The goal is to use a variety of observational techniques and instruments, and to reduce, interpret, and synthesize groundbased astronomical data concerning the comets, asteroids, and other small bodies of the solar system in order to study the compositions, physical characteristics, population properties, and evolution of these bodies.

b. This year's research has involved five distinct efforts. Chapman has studied asteroids and faint cometary nuclei, with emphasis on synthesizing groundbased databases to determine surface mineralogies and population characteristics; many new results on taxonomy, size-distributions, and asteroid family traits have been obtained. Weidenschilling, Davis, and Chapman have reduced and published a 5-year lightcurve database on large, rapidly-rotating asteroids, and are involved in observations to fill in gaps in ecliptic longitude coverage and to infer body shapes. Hartmann has studied asteroids, Trojans, and comets using colorimetric, photometric, and spectrophotometric techniques and has clarified relationships among the various classses of primarily outer-solar-system bodies. Davis and Campins have renewed our earlier efforts to detect and study vulcanoids (hypothesized small bodies interior to Mercury's orbit) using more sensitive daytime IR techniques, in collaboration with others. Campins has used detector arrays for IR photometry and dynamical analysis of images of comets to study cometary dust. Chapman, Campins, and others have performed a variety of programmatic tasks, as well, including Chapman's chairmanship of the Planetary Astronomy M.O.W.G.

c. Proposed research during the first year of the 3-year period will continue the earlier directions, with some shift towards interpretation and synthesis in support of the 1988 Asteroids Meeting, of which Binzel is Co-Organizer. A variety of observations will continue at Mauna Kea, Kitt Peak, Mt. Lemmon, and elsewhere. Some data analysis will be performed on the P.S.I. Image Processing System. Some proposed research tasks, as well as programmatic activities, are contingent on adequate funds.

d. Numerous publications are summarized on the attached sheet.

Compositional Structure of the Asteroid Belt and Its Families, Clark R. Chapman, 1987 to be submitted to Icarus.

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Physics, Chemistry and Collisional Evolution of the Asteroids, Clark R. Chapman, 1987, proceedings of Enrico Fermi School of Physics, in press.

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A Comparison of the Continuum Colors of P/Halley, Other Comets, and Asteroids, W.K. Hartmann and 5 other authors, 1986, submitted to Heidelberg Proceedings on Comet Halley.

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Trojan and Hilda Asteroid Lightcurves. 2: Anomalously Elongated Shapes among Trojans (and Hildas?), William K. Hartmann, David J. Tholen, Jay Goguen, Richard P. Binzel, and Dale P. Cruikshank, 1987, in preparation.

Albedo Maps of Comets P/Halley and P/Giacobini-Zinner, H. Campins and 5 other authors, 1987, Astronomy and Astrophysics.

Thermal-Infrared and Visual Imaging of Comet Giacobini-Zinner, H. Campins and 9 other authors, 1986, Astro. J. 310. L61-L65.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Imaging and Spectroscopy of Comet P/Halley (NASW-4170)

PERFORMING ORGANIZATION

Atmospheric and Environmental Research, Inc.
840 Memorial Dr.
Cambridge, MA 02139

INVESTIGATOR'S NAME

Michael R. Combi

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. The goals of this investigation are the reduction and analysis of a large set of high-resolution echelle/reticon spectra and IAU narrow-band-filtered CCD images taken of comet P/Halley during the pre-perihelion period at Oak Ridge Observatory (CFA/SAO). The scientific objectives associated with these goals are the determination of the spatial distributions of several important radicals, atoms and ions. These include C_2, CN C_3, NH_2, $O(^1D)$, H_2O^+, and CO^+. The observations of the neutral species, when combined with our realistic models, will aid in our understanding of their production and decay mechanisms as well as serve as important indicators of the physical conditions in the inner coma. The spatial maps and spectra of ions will serve as a guide to constrain the very complex models necessary for understanding the interaction of the solar wind flow and the cometary ions.

b. Progress during the prior year, the first year of this project, was made mainly in the area of the basic reduction of the CCD images. All of the comet images have been bias subtracted and flat-fielded and the reduction of the calibration star images is in progress as of this writing.

c. Efforts in this (second) year will concentrate first on the final absolute calibration of the CCD image frames and emission-continuum frame subtraction to isolate the two-dimensional sky-plane distributions of particular species emissions. Recent advances in our Monte Carlo particle trajectory models will then enable us to begin analyzing the radiation-pressure distorted comae in the light of the neutral carbon bearing radicals. This will yield important information regarding the velocity distributions of the radicals in the observed transition region from collision-domintated to free flow. Work will also begin to identify the many features seen in the spectral-survey coverage of the nucleus-centered echelle-reticon data, and in measuring unambiguously the NH_2 to $O(^1D)$ ratio near 6300A at various locations in the inner coma of comet Halley.

d. As we near the end of the first calendar year of this project no formal publications have as yet been submitted.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Research in Planetary Studies, and Operation of Mauna Kea Observatory

PERFORMING ORGANIZATION

Institute for Astronomy
University of Hawaii
Honolulu, Hawaii

INVESTIGATOR'S NAME

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DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) This investigation concentrates on observational and interpretational studies of solar system bodies, the planets, their satellites, the asteroids and comets. Observations are made at all visual wavelengths and in the infrared using the telescopes and instruments at the Mauna Kea Observatories. The prime telescope for this work is the NASA-built 2.24-m telescope of the Univ. of Hawaii.
b) Principal accomplishments in the interval Jan. 1986-May 1987 include: i) determination of the physical and orbital parameters of Pluto and Charon, including their diameters and the mean density of the system; ii) acquisition of the best images of Neptune ever taken; iii) discovery of major changes in the spectrum of Triton indicating changes on the surface or in the atmosphere; iv) detection of a non water-ice volatile on Europa and its apparent time variability; v) determination of the sulfur isotopic content of the snows of Io; vi) discovery of the C-H organic signature in the infrared spectrum of the wet C-type asteroid 130 Elektra; vii) acquisition of the first spectrum of Pluto's satellite, showing water ice on the surface; viii) photometry of 11 planet-crossing asteroids; ix) acquisition of a huge body of data on Comet Halley; x) breakthrough in modeling of thermal inertias and thermal conductivities of solar system bodies.
c) The atmospheric activity of Neptune will be monitored by means of CCD imagery through selected filters in support of the Voyager encounter with that planet in August 1989. We will continue to expand the data base on this planet with observations before, during, and after the encounter. Also in support of Voyager, we will continue our spectroscopic study of Triton, its surface and atmosphere. We will continue our IR spectroscopic study of the satellites of Jupiter, Saturn, Uranus, and Pluto to establish more details of their volatile content and their possible time variability. We will continue our IR thermal studies of Io's volcanoes to monitor their activity and establish the global thermal budget of the satellite. We will continue our observations of Pluto and its satellite to refine the dimensions and orbits of these bodies, and to model the surface distribution of volatiles. We will continue photometric/spectroscopic studies of asteroids, with special emphasis on near-earth bodies and the dark bodies of the outer asteroid system. We will continue theoretical work on thermal properties of solar system bodies in support of the observational work on the ground and from spacecraft. In return for NASA's contribution to the operation of the 2.24-m telescope, 30% of the time will be assigned to investigators working on planetary problems of interest to NASA.

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Hartmann, W. K., D. J. Tholen, and D. P. Cruikshank (1987). The relationship of active comets, "extinct" comets, and dark asteroids. Icarus 69, 33-50.

Piscitelli, J. R., D. P. Cruikshank, and J. F. Bell. (1986). Laboratory studies of irradiated nitrogen-methane mixtures: Application to Triton. Icarus (submitted).

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Tholen, D. J., D. P. Cruikshank, W. K. Hartmann, N. Lark, H. B. Hammel, and J. R. Piscitelli (1986). A comparison of the continuum colors of P/Halley, other comets, and asteroids. 20th ESLAB Symposium on the Exploration of Halley's Comet, ESA SP-250, Vol. III, pp. 503-507.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Spectroscopic Planetary Detection

PERFORMING ORGANIZATION

Planetary Systems Branch
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME

D. Deming/M. Mumma/T.Kostiuk

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) This task supports the detection of extra-solar planetary systems using spectroscopic means. The strategy of the investigation is to validate the spectroscopic detection method by measuring the velocity stability of integrated sunlight and comparing any observed variations to the magnitude of the Doppler reflex produced by a Jupiter-mass planetary companion. Observations are conducted in the infrared to achieve the maximum instrumental stability.

b) In FY87 several years (1983-85) of Fourier transform (FTS) data were analyzed, and a 30 meter/sec change in the apparent velocity of integrated sunlight was obtained. The effect is of solar origin. Presuming it is periodic with the solar cycle, it will mimic the effect produced by an approximately 2 Jupiter mass companion. This result was published in the Astrophysical Journal. Also in FY87, additional FTS observations were obtained, as well as additional data using the laser heterodyne spectrometer.

c) In FY88 additional FTS and laser heterodyne data will be obtained and analyzed. Several refinements in the observing procedures will be implemented. For example, we will use an isotopic gas absorption cell to reduce contamination of our velocity calibrations by weak absorptions in the terrestrial atmosphere. The nature of this investigation does not justify publication of the results on a yearly basis. Publication of further results is anticipated to be appropriate after several more years.

d) Publications

"On the Convective Noise Floor for the Spectroscopic Detection of Low Mass Companions to Solar Type Stars," D. Deming et al., in the proceedings of a workshop held at George Mason University (October 14-15, 1985) on "The Astrophysics of Brown Dwarfs," eds. Kafatos and Harrington (Cambridge University Press), 1986.

"On the Apparent Velocity of Integrated Sunlight I. 1983-1985," D. Deming et al., Astrophysical Journal, May 15, 1987

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Speckle Interferometry of Asteroids

PERFORMING ORGANIZATION

University of Arizona

INVESTIGATOR'S NAME

Jack D. Drummond

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Speckle interferometry is a high angular resolution technique that allows the determination of an asteroid's size, shape, and pole orientation from the changing outline of the projected asteroid. In previous years we have been restricted to studying the two-dimensional power spectrum or autocorrelation, and have obtained information on 433 Eros, 532 Herculina, and 511 Davida.

b) During the past year we have made a concerted effort to obtain reconstructed images from the power spectrum and phases. We have been successful in obtaining the first-ever images of the surface of an asteroid, 4 Vesta, that clearly show detailed surface markings. To further the interpretation of these series of images, we have developed a computer program that will display a theoretical lightcurve for any triaxial ellipsoid shape with any number and size of bright or dark "spots". From the images of Vesta from speckle interferometry, and through the computer simulation we have determined the size, shape, and pole of Vesta, and have found that one hemisphere is so dominated by extensive dark areas that a minimum occurs in the lightcurve when the maximum cross sectional area is visible. Thus the lightcurve has only one max/min per period instead of the two associated with its triaxial ellipsoid shape.

c) This year we intend to obtain more images of Vesta from data taken with a different camera at a different epoch. If the two sets of images show agreement we will expand our efforts of asteroid imaging to other minor planets, in particular the ones with apparent large scale albedo structure such as 532 Herculina and 16 Psyche. We are also enlarging our repertoire of tools to study the asteroids. In addition to speckle interferometry and our theoretical lightcurve programs, we have developed and will continue to apply photometric astrometry, amplitude-aspect, and magnitude-amplitude-aspect methods in order to determine asteroids' poles and shapes from photometric data (lightcurves).

d) Drummond, J. D. and E. K. Hege: Speckle Interferometry of Asteroids. III. 511 Davida and its Photometry. Icarus 67, 251, 1986.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Portable High Speed Photometry Systems for Observing Occultations

PERFORMING ORGANIZATION

Department of Earth, Atmospheric and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139

INVESTIGATOR'S NAME

James L. Elliot, Principal Investigator
Edward W. Dunham, Co-Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. **Strategy:** Because of their high spatial resolution, stellar occultations have proven extremely effective for learning about planetary upper atmospheres, asteroids, and planetary rings. Our ring orbit studies for Uranus have been particularly fruitful because we have been able--through occultations--to obtain data of high spatial resolution (~2 km) at the rate of 1-2 times per year. Our occultation program at M.I.T. involves (i) identifying the scientific questions that can be answered by occultation events, (ii) predicting the zone of visibility for the useful events, (iii) maintaining and improving a set of portable high-speed photometric systems, (iv) obtaining the observations, and (v) reducing the data and interpreting the results.

b. **Accomplishments:** We completed analysis of the high-quality Uranian rings occultation data that we obtained in 1985, and we achieved the following goals: (i) the precision of our ring precession rates improved by a factor of 20, which makes our orbit model sensitive to an icy shepherd satellite with a diameter of 8 km that is 100 km distant from a ring; (ii) the precision of our values for the harmonic coefficients of the Uranian gravity field, J_2 and J_4, also improved by a factor of 20, and (iii) the improved reference system for the ring orbits will allow us to obtain a considerably more accurte value for the planetary oblateness of the Uranian upper atmosphere that we have determined from our observations of previous planetary occultations. The results of (i) and (ii) have been submitted for publication in Icarus. We also obtained observations of the "four-day" occultation by the Uranian rings (during the period March 30 - April 2, 1987) from a worldwide network of observatories: Siding Spring, Mount Stromlo, Sutherland, Cerro Tololo, and Mauna Kea.

c. **Anticipated Accomplishments:** We are now analyzing our data from the "four-day" occultation, which involved a star of unusally small angular diameter, so that the data show greater spatial resolution than any yet obtained from the ground. From this work, we should be able to characterize the width variations of the rings as a function of longitude - one of the outstanding dynamical problems of this ring system. Also we are upgrading our SNAPSHOT CCD camera to use for more precise predictions of stellar occultations by outer solar system bodies of small angular diameter, such as Pluto.

4.d. Publications (1986-87)

Bosh, A.S., Elliot, J.L., Kruse, S.E., Baron, R.L., Dunham, E.W., and French, L.M.: Signal-to-Noise Ratios for Possible Stellar Occultations by Pluto. Icarus 66, 556, 1986.

Covault, C.E., and French, L.M.: JHK Photometry of Uranus and Neptune Occultation Candidate Stars: 1986-1990. Icarus 66, 630, 1986.

Covault, C.E., Glass, I.S., French, R.G., and Elliot, J.L.: The 7 and 25 June 1985 Neptune Occultations: Constraints on the Putative Neptune "Arc". Icarus 67, 126, 1986.

Elliot, J.L., Glass, I.S. French, R.G., and Kangas, J.A.: The Occultation of KME 17 by Uranus and Its Rings. Icarus (in press).

French, R.G., Elliot, J.L., French, L.M., Kangas, J.A., Meech, K.J., Ressler, M.E., Buie, M.W., Frogel, J.A., Holberg, J.B., Fuensalida, J.J., and Joy, M.: Normal Modes and Resonances in the Uranian Rings: Results From Earth-Based and Voyager Occultation Observations. Submitted to Icarus.

French, R.G., Elliot, J.L., and Levine, S.E.: Structure of the Uranian Rings. II. Ring Orbits and Widths. Icarus 67, 134, 1986.

French, R.G., Kangas, J.A., and Elliot, J.L.: What Perturbs the γ and σ Rings of Uranus. Science 231, 480, 1986.

French, L.M., Morales, G., Gaiser, S.L., and Frogel, J.A.: Photometry of Occultation Candidate Stars: II. Uranus 1985-1990 and Saturn 1986-1991. Icarus 67, 540, 1986.

Kruse, S., Klavetter, J.J., and Dunham, E.W.: Photometry of Phoebe. Icarus 68, 167, 1986.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Spectroscopy

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 35721

INVESTIGATOR'S NAME

Uwe Fink (602)621-2736

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a)The main goal of our research is CCD spectroscopic and imaging studies of the solar system in support of spacecraft investigations. Our studies include the physical behavior of comets, the atmospheres of the gaseous planets, and the solid surfaces of satellites and asteroids. In recent years we have concentrated on studies of the gaseous and solid emanations of comets using the techniques of CCD spectroscopy and imaging.

b)The start of the last proposal period was still dominated by intensive imaging and spectroscopic observations of comet P/Halley. We then shifted to the time consuming task of spectroscopic data reduction much of which was completed for the Heidelberg comet meeting and the Paris DPS meeting where several papers were presented. We also assembled a set of illustrations for the "Atlas of Cometary Spectra" by Delbouille et al. Our spectra cover the region from 5200 to 10400 A at a spectral resolution of ~12 A; their spatial extent is 200" along the slit. A variety of spatially resolved spectra with the slit along the tail and perpendicular to the tail were recorded. Emission species observed are C_2, CN, NH_2, H_2O^+, [OI] and NaI. Na emission was observed strongly only in our 1986 March data. During 1986 August and September, a number of emission features were seen which we have not yet identified. Our data analysis program was interrupted by extensive further Halley observations (about 50 nights) this spring brought about by the controversy over Halley's rotation period. The observational part of this program has just been completed and we have turned the data over to Dr. Mike Belton (who is a co-investigator on this project) for analysis. A surprising result of this program was an outburst in Halley's brightness by 1.3 magnitudes on April 23 when the comet was 5.5 AU from the sun (IAU circular #4372). During this observation period we also obtained some very high quality spectra of Pluto and Charon during an eclipse and spectra of Mercury to search for pyroxene features. In addition our CCD system has been used extensively by a large number of LPL investigators (Drs. Hunten et al., Gehrels et al. and Tomasko et al.) as well as Steward Observatory and Space Telescope personnel putting a large strain on our time and financial resources.

c)Our emphasis is now shifting to data analysis. We will concentrate on the following investigations: the H_2O production rates for P/Halley with heliocentric distance using our spectroscopic [OI] observations; the spatial distribution of [OI] using our narrow band images; the singlet-triplet intercombination probability of C_2 using our detection of the C_2 Phillips bands; the spatial distribution and column density of H_2O^+ using both our spectroscopic and imaging data. Finally we need to reduce and publish our time-critical Pluto-Charon data and our Mercury observations.

Papers Published/In Progress

R. Hofmann, H. P. Larson and U. Fink, "The 4 um Spectra of Compact Infrared Sources," Astron. Astrophys, 160, 18-24 (1986).

U. Fink, M. DiSanti and A. Schultz, "The Spectral Development of Comet P/Halley from 1985 August to 1986 June," Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, ESA SP-250, Vol. III, (1986).

M. W. Buie and U. Fink, "Methane Absorption Variations in the Spectrum of Pluto," Icarus, in press.

Published Abstracts of Papers Presented

U. Fink, M. DiSanti and A. Schultz, "The Spectral Development of Comet P/Halley from 1985 August to 1986 June," 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, Germany, Oct. 27-31, 1986.

M. DiSanti, U. Fink and A. Schultz, "The Intensity of the OI ^{1}D Emission of Comet P/Halley during the Course of Its Recent Apparition," 20th ESLAB Symposium on the Exploration of Halley's comet, Heidelberg, Germany, Oct. 27-31, 1986.

U. Fink, M. DiSanti and A. Schultz, "Observations of H_2O^+ in Comet Halley," 18th Annual DPS/AAS Meeting, Paris, France, Nov. 4-7, BAAS, 18, 812 (1986).

M. DiSanti, U. Fink and A. Schultz, "Spectroscopy of the 1D Line of [OI] in Comet Halley," 18th Annual DPS/AAS Meeting, Paris, France, Nov. 4-7, BAAS, 18, 812 (1986).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

The University of Pittsburgh's Allegheny Observatory Search for Planetary Systems

PERFORMING ORGANIZATION

The University of Pittsburgh's Allegheny Observatory

INVESTIGATOR'S NAME

George D. Gatewood, Ph.D.

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

The University of Pittsburgh's Allegheny Observatory Search for Planetary Systems employs high precision astrometry to detect the small perturbations a planetary system would impart to the motion of its star. The major problems encountered in previous approaches to planetary detection have been: 1)systematic errors associated with telescope design, and 2) accidental errors associated with the detector. The potential for the first of these has been greatly reduced by the replacement of the 75-year old, 30-inch photographic objective of the Thaw refractor with a modern design of highest quality optical glass mounted in a dynamic stainless steel cell (Gatewood et al.: "A New Astrometric System. In Astrometric Techniques," IAU Col. #109). The second error source has been greatly reduced by the development of a new astrometric detector, the MAP (Gatewood, G.: The Multichannel Astrometric Photometer and Atmospheric Limitations in the Measurement of Relative Directions. Astron. J. 92, 1987). The MAP achieves astrometric precisions of 0.003 arc seconds per hour of observation, nearly twice the precision of an annual normal point from the old photographic program.

Full time observations began in the spring of 1986. The full program includes 24 stars with detection capabilities of one-tenth to one Jupiter mass in a 12-year orbit. Current theory would suggest a high probability of at least one detection in the survey, which includes a wide range of spectral types. However, analysis of the data also yields well defined statistical boundaries to any negative result. Thus, a negative result in the 20-year long program will be both profound and well-defined.

REFEREED PAPERS

"A New Astrometric System", TRANSACTIONS OF IAU SYMPOSIUM 109, 1986 (Refereed Astrometric Publications) (author with John Stein, Charles DiFatta and Joost Kiewiet de Jonge). "Astrometric Techniques", pp. 341-352 (edited by Eichhorn and Leacock)

"A Preliminary Look at Astrometric Accuracy as a Function of Photon Counts", AMERICAN ASTRONOMICAL JOURNAL Vol. 90, 2397, 1985. (author with John Stein, Charles DiFatta, Joost Kiewiet de Jonge, and Lee Breakiron)

"The Astrometric Telescope Facility", Proceed of SPIE 628, 1986. (co-author with E.H. Levy, J.W. Stein and R.S. McMillian

"The Multichannel Astrometric Photometer and Atmospheric Limitations in the Measurement of Relative Positions", AMERICAN ASTRONOMICAL JOURNAL, 91, 1987. (author)

NON-REFEREED PAPERS

"A New Objective for the Allegheny Observatory 30-inch Refractor", 1985, The Search for Extraterrestrial Life: Recent Developments, 65-74 (edited by M.D. Papagiannis)

"NASA's Astrometric Telescope Facility", 1987, with Jeffrey Scargle and Kenji Nishioka, Ames Research Center. IAU Celebration of the 100th Anniversary of the Cart du Cel", Paris, France

"Performance Considerations for the Astrometric Telescope Facility in the Phase I Space Station", 1987, SPIE, Cannes, France

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

CCD Scanning for Asteroids and Comets

PERFORMING ORGANIZATION

Lunar & Planetary Laboratory and Steward Observatory
The University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Tom Gehrels , Principal Investigator
R. S. McMillan, Co-Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

Gehrels, Scotti, and McMillan report the continuation of CCD scanning for comets and asteroids with the Spacewatch Telescope which is the 0.91-m Newtonian reflector of the Steward Observatory on Kitt Peak. A total of 242 nights have been used between April 22, 1984 and Feb. 26, 1987. The "Six sigma" limiting magnitude is 19.6 with an effective exposure time of 1 minute. As of Feb. 26, 1987, 69 new asteroids have been reported. Of these, 16 have had orbits determined by positions spanning intervals of several days to 15 months. One is a Hilda-type, and one is in the rare 2:3 resonance region. In addition, astrometric observations have been reported to Co-investigator B. G. Marsden at the Minor Planet Center for more than 72 recovered asteroids, 40 of which the MPC was able to "number" after our observations, and 44 previously known comets, of which 9 were first recoveries at the current apparition. This astrometry is done with the new technique of turning the telescope drive off whereby the object and several SAO-standards come, all at nearly the same airmass, through the field of the scanning CCD.

We intend to continue the astrometry during following years with a monthly list of objects provided by Marsden and we add to that the special requests from Ostro and others for radar targets and special objects such as Comet Tempel 2. In the laboratory and office we are working on the next phase of the Spacewatch program which is to install a Tektronix 2048 CCD which is on order and an infrared CCD capability as well.

Publications

The Minor Planet Cirulars give the monthly reports on comet and asteroid observations made by the Spacewatch Telescope.

"Use of a scanning CCD to discriminate asteroid images moving in a field of stars," R. S. McMillan, J. V. Scotti, J. E. Frecker, T. Gehrels, and M. L. Perry, in Proceedings of the S.P.I.E., **627**, Instrumentation in Astronomy - VI, ed. D. L. Crawford, 1986, pp. 141-154.

"On the feasibility of observing small asteroids with the Galileo, Venera, and Comet-Rendezvous-Asteroid-Flyby Missions," T. Gehrels, Icarus **66**, 288-296, 1986; also in Astron. Vestnik, **20**, No. 4, 306-318, 1986 (in Russian).

"Astrometry with a scanning CCD," T. Gehrels, B. G. Marsden, R. S. McMillan, and J. V. Scotti, Astron. J. **91**, pp. 1242-1243, 1986.

"CCD search for geosynchronous debris," T. Gehrels and F. Vilas, Icarus, **68**, 412-417, 1986.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Physical Studies of Fast Moving Asteroids

PERFORMING ORGANIZATION

Lunar & Planetary Laboratory and the Steward Observatory
The University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Tom Gehrels, Principal Investigator
W. Z. Wisniewski, Co-Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

Gehrels, McMillan and Wisniewski report that routines have been developed for CCD photometry of asteroid lightcurves. The first results were obtained on Asteroid 1985 RV. In addition, the regular UBVRI photometer is used for brighter objects, for both lightcurves and photometry. Results on 1986 EB, Asteroid 3103 and Asteroid 594 are being prepared for publication. In a joint project with Belton and Fink an extensive project is on the way in photometry of Comet Halley. An increase in brightness was noticed and this flaring has been reported in the Circular 4372 of the International Astronomical Union. The highlight of our observations is that in a sample of seven Earth-approaching asteroids only one was definitely of type S, a type that was previously believed to be predominant among AAA asteroids. While concentrating our observing on asteroids smaller than 10 km in diameter we more than doubled the number of objects with period of rotation of less than 3 hours.

Publications

"Differential CCD photometry of faint asteroids in crowded star fields and non-photometric sky conditions," W. Z. Wisniewski and R. S. McMillan, Astron. J. **93**, 1264-1267, 1987.

"Photometry of six radar target asteroids," W. Z. Wisniewski, Bull. Amer. Astron. Soc. 19, 633, 1987 (abstract).

"Photometry of AAA asteroids, W. Z. Wisniewski, Bull. Amer. Astron. Soc. 19, 633, 1987 (abstract).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

High-Resolution Imaging of Solar System Objects

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

B. A. Goldberg, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. This work unit supports physical studies of the near-nucleus regions of comets plus Io an its neutral sodium cloud as continuing programs, and Mars as a new initiative. Determining th kinematic and spectrophotometric properties of Halley and the CRAF candidates will be emphasiz ed in the comet program, as well as continued comparative analysis of groundbased and in situ measurements of Giacobini-Zinner (GZ) to further characterize the ion tail and near-nucleus dust environment. The Io sodium program will better define the cloud's behavior and source based on further interpretation of the Table Mountain data set which has been extensively re-processed. Observations of Mars will be directed primarily at determining the seasonal cycles of dust and the morphology and evolution of the great dust storms. The rationale for implemen tation of these varied programs is the availability of a unique data base and/or particularly advantageous situations for conducting groundbased observations. The overall strategy is to obtain and utilize high-resolution, calibrated images to determine the desired kinematic, morphological, and spectrophotometric properties of the objects of interest.

B. Comets: Continued analysis of CCD imaging data taken through IHW filters on 3.6m Canada-France-Hawaii Telescope (Halley 12/84-2/87, GZ during ICE encounter, and several more comets) Results include a new interpretation of the appearance and behavior of cometary ion tails -- based on comparative analysis with ICE magnetic field data, characterization of the near-nucleus region of Halley during significant periods of its apparition, and support of IR studies Initiated comparative analysis of groundbased and ICE dust measurements of GZ and developed a new capability for carrying out comet imaging programs at AMOS Observatory (Maui). Io Sodium: Near-term objectives for re-processing of sodium data set completed, providing significantly more accurate brightness values near Io. Mars: Initiated preliminary high-resolution test measurements at AMOS and determined requirements for implementation of observing program.

C. Continue physical study of near-nucleus regions of comets based in part on new observations at CFHT and AMOS emphasizing Halley, GZ, and CRAF candidates. Specific goals will include the determination of rotation periods and the nature and levels of activity of the relevant comets Continue analysis of Io sodium cloud, emphasizing interpretation and publication of observational data already obtained; specifically, further analysis of stability, systematic variations, and nature of source region. Initiate Mars observing program to take advantage of the excellent 1988 apparition and availability of unique instrumentation. Program at AMOS will be supplemented by USAF funding.

D. One journal paper (GRL), two papers in symposia proceedings, four symposia abstracts.

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OF POOR QUALITY

PUBLICATIONS LIST 1986-87

B. A. Goldberg, May 1987

Goldberg, B. A. et al. 1986, "High-Resolution Imaging Studies of the Near-Nucleus Regions of Comets", Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, 27-31 October, ESA SP-250 (December 1986), pp. 153-156.

Goldberg, B. A. 1986, "Timely Visits Within Our Solar System", Exhibit for National Academy of Sciences, Washington, D. C.

Slavin, J. A., Goldberg, B. A. et al, "The Structure of a Cometary Type I Tail: Ground-Based and ICE Observation of P/Giocobini-Zinner", Geophys. Res. Lett. 13, No. 11, pp. 1085-1088.

Slavin, J. A., Goldberg, B. A. et al. 1986, "The P/Giacobini-Zinner Magnetotail", Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, 27-31 October, ESA SP-250 (December 1986), pp. 81-87.

Goldberg, B. A. et al. 1987, "High-Resolution Imaging Studies of the Near-Nucleus Region of Comets", Symposium on the Divirsity and Similarity of Comets, Brussels, Belgium 6-9 April.

Four additional symposium abstracts (for DPS, AAS, Heidelberg).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Astronomy: Rings, Satellites, and Asteroids

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85719

INVESTIGATOR'S NAME

Richard Greenberg

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Strategy: Studies of planetary rings focus on the dynamical processes that govern astronomically observable ring properties and structure. These investigations thus help reveal properties of the rings as well as probe the gravity fields of the planets. Satellite studies involve interpretation of orbital motion to extract information regarding the gravity fields of the outer planets and the physical properties of the satellites themselves. Asteroid lightcurve work is designed to investigate the large-scale shapes of the asteroids, as well as to reveal anomalous features such as major topography, possible satellites, or albedo variations.

b) Progress: Major advances have been made in understanding the nature of viscous transport in planetary rings, and the role of individual particles' physical properties. The classical determination of the masses of Mimas and Tethys from astrometric data has been reviewed and found correct; Published Voyager results apparently need revision. With collaborators, a paper describing results from a five-year program of lightcurve acquisition has been prepared.

c) Proposed Research: The new results on viscosity will be applied to models of Neptunian ring arcs, Uranian rings, and Saturnian ring structure. Uranian ring occultations will be studied for evidence of local swarms of small bodies. Lightcurves will be searched for evidence of irregularities and albedo variations, as well as global structure. Correlation will be made with infrared lightcurves.

d) Summary Bibliography: 3 papers, 2 abstracts, 2 presentations.

Publications by Richard Greenberg (Supported by NASA Planetary Astronomy)

Greenberg, R.: Particle Properties and the Large-scale Structure of Planetary Rings. Icarus, submitted 1987.

Spaute, D., and R. Greenberg: Collision Mechanics and the Structure of Planetary Ring Edges. Icarus, in press, 1987.

Weidenschilling, S.J., et al.: Photometric Geodesy of Main-Belt Asteroids. Icarus, in press, 1987.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Submillimeter Heterodyne Receiver for the CSO Telescope

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

S. Gulkis, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. This task is to build a cryogenically cooled 620-700 GHz astronomical receiver that will be used as a facility instrument at the Caltech Submillimeter Observatory on Mauna Kea, Hawaii. The receiver will have applications as a very high resolution spectrometer to investigate spectral lines in planetary and satellite atmospheres, and comets. The receiver will also be used to make continuum measurements of planets, satellites, and asteroids.

b. Work was started on a solid-state local oscillator source. Toward this goal, a quadrupler which multiplies a Gunn oscillator from 85 GHz to 340 GHz was designed, fabricated, and successfully tested.

A technical approach for an SIS mixer was developed, and sources of the junctions located. A lower frequency (200 GHz) test setup was designed and fabricated.

A (CSO-compatable) cryostat for use on the telescope was purchased. Engineering design studies were begun to interface the receiver to the CSO telescope.

c. The major effort during the second year of this task will be to obtain the local oscillator source and to progress toward constructing the SIS mixer device itself. A breadboard 200 GHz SIS mixer will be assembled and tested to guide the work on the higher frequency mixer.

d. "Submillimeter Heterodyne Receiver for the Caltech Submillimeter Telescope on Mauna Kea", Gulkis, S., Frerking, M.A., Swanson, P.N., Wannier, P., and Wilson, W.J.; Proposal submitted to the NASA Aeronautics and Space Administration Office of Space Science and Application.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Research in Planetary Astronomy and Operation of the 2.2-Meter Telescope

PERFORMING ORGANIZATION

Institute for Astronomy
University of Hawaii
2680 Woodlawn Drive
Honolulu, HI 96822

INVESTIGATOR'S NAME

Donald N. B. Hall

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

The NASA-IRTF continues to be recognized worldwide as one of the best ground-based infrared astronomical research facilities and the only one which is especially equipped for observations of solar systems bodies. The Facility's unique capability for planetary research is the result of NASA's emphasis on support for solar system exploration missions. The University of Hawaii (UH) served as prime contractor during the construction of the Facility and assumed operational responsibility in October of 1979. Thus, both operation of the Facility and implementation of NASA's programatic requirements for the IRTF have been the responsibility of UH for over six years. Given this baseline of successful operation and enhancement of the IRTF, UH has been responsible for the following general tasks:

- Maintaining a basic level of effort or core operation of the IRTF.
- Providing annual recommendations to NASA for enhancements to the IRTF which are justified by either evolution of the IRTF's science mission or by unique scientific opportunities. Implementation of these opportunities would become the responsibility of UH if so directed by NASA.
- Operation of a continuing program, supported primarily from sources outside NASA, to provide advanced focal plane instrumentation for the IRTF.

The overall operation of the IRTF would continue under the terms of the IRTF Management Plan, as amended January 1, 1983. The general responsibilities of the involved parties are set down in that plan and will not be restated here.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Photometry of Comets

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

M. S. Hanner, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Selected comets are observed in the near-infrared (1–2.2 μm) and thermal infrared (3.5–20 μm) with the NASA Infrared Telescope Facility and other telescopes as appropriate. The scientific objectives are to characterize the thermal emission from the dust coma, derive dust production rates, detect silicate features near 10 and 20 microns, compare thermal and scattered radiation in order to derive average albedo of the grains, and detect changes in the thermal emission which indicate changes in grain size or composition with heliocentric distance as well as differences among comets. Knowledge of the dust environment is essential to S/C design and mission planning for NASA's CRAF mission.

b. 1) Halley images obtained with JPL's linear array at the AAT have been processed (5); a full paper is in progress. Distinct changes in the structure of the inner coma can be seen in a few hours. 2) IRTF monitoring program is complete: 2 papers published (2,3), third in progress. 3) Workshop on Halley infrared data planned for August 1987. 4) IRTF runs planned for May, July, Sept. 1987 to observe Wilson and several short-period comets.

c. Plans for FY 88 are: .1) Complete analysis of Halley, Wilson data. 2) Observe several short-period comets at .he IRTF, with emphasis on the silicate features. 3) Conduct concerted observing program for Tempel 2, target of CRAF mission. 4) Image the inner dust coma with JPL's 128 x 128 near-infrared area array when it becomes available.

d. 1.) A Preliminary Look at the Dust in Comet Halley. M. S. Hanner, *Adv. Space Res.* 5, No. 12, 325, 1986.

2.) The NASA Infrared Telescope Facility Comet Halley Monitoring Program I. Preperihelion Results, A. T. Tokunaga et al., *Astron. J.* 92, 1183, 1986.

3.) Infrared Emission from Halley's Dust Coma during March 1986. M. S. Hanner, A. T. Tokunaga, W. F. Golisch, D. M. Griep, C. D. Kaminski. *Astron. Astrophys.*, in press, 1987.

4.) Comet Sugano-Saigusa-Fujikawa (1983V). M. S. Hanner, R. L. Newburn, H. Spinrad, G. J. Veeder; submitted to *Astron. J.*, March 1987.

5.) IR Imaging with JPL's Linear Array Camera. M. S. Hanner, P. N. Kupferman, G. Bailey and J. C. Zarnecki. Proceedings of Hilo Workshop on Infrared Array Detectors, 24–26 March 1987.

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Dust Density and Mass Distribution Near Comet Halley from GIOTTO Observations, J. A. M. McDonnell et al. Nature 321, 338, 1986.

The Comet Halley Dust and Gas Environment, N. Divine et al. Space Science Reviews, 43, 1-104, 1986.

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IR Imaging with JPL's Linear Array Camera. M. S. Hanner, P. N. Kupferman, G. Bailey and J. C. Zarnecki. Proceedings of Hilo Workshop on Infrared Array Detectors, 24-26 March 1987.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Table Mountain Observatory Support to Other Programs

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

A. W. Harris, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. The Table Mountain Observatory (TMO) facilities include well equipped 24" and 16" telescopes with a 40" (1m) telescope (owned by Pomona College) due for completion during FY 87. This proposal is to provide operational support (equipment maintenance, setup, and observing assistance) at TMO to other programs.

b. The program currently most heavily supported by this grant is the asteroid photometry program directed by A. Harris. During CY 86, about 20 asteroids were observed, including two near-Earth asteroids. An occultation of a star by the asteroid 10 Hygiea was successfully observed. Two summer students were trained and assisted in their observing projects involving asteroid photometry. The photometric observations are used to derive rotation periods, estimate shapes and pole orientations, and to define the phase relations of asteroids. Several programs of Comet Halley observations were supported during 1985-86. In addition to synoptic coverage with the 10" Schmidt camera, the JPL CCD camera was used for large scale imaging on the 24" telescope, and observations by David Rees, Univ. College London, were supported to obtain narrow spectral band images of Halley before and during the Giotto encounter. Limited support was provided to students and faculty from the Claremont Colleges for variable star observing programs.

c. We propose to continue the asteroid program, with emphasis on measuring phase relations at very low and very large phase angles, and supporting collaborative studies of asteroid shapes. Efforts will be made to observe occultations by asteroids, and to obtain lightcurves so that the rotation phase at the time of occultation will be known. Asteroids which are planned for radar observations will be given special attention, as the combination of radar and photometric data is much more valuable than either observation separately. The JPL CCD camera will be maintained as a TMO facility instrument. The Rees narrow band camera is at TMO and will be used as comet targets become available. Other observing programs will be supported as scheduled on the telescopes, as resources permit.

d. 1) Harris, A.W. (1986) On the opposition effect of high albedo asteroids: 44 Nysa. BAAS 18, 797. 2) Harris, A.W. (1987) Fourier analysis of asteroid lightcurves; some preliminary results. Lunar and Planetary Science XVIII, 385-386. 3) Harris, A. W., et al (1986) Photoelectric lightcurves of the asteroid 1862 Apollo. Icarus 70, in press. 4) Harris, A.W., et al (1987) Photoelectric observations of asteroids 3, 24, 60, 261, and 863. Subm. to Icarus. 5) Rees, D., et al (1986) Networking ground-based images of Comet Halley during the Giotto Encounter. EOS 67, 1385-1387. 6) Rees, D., et al (1986) Optical observations of ion tail structures and velocity flows in Comet Halley during the period of the five spacecraft encounters. Adv. Space Res. 5, 255-261. 7) Sterken, C., et al (1986) BW Vulpeculae: a coordinated campaign of photoelectric photometry from thirteen observatories. Astron. Astrophys. Sup. Ser. 66, 11-35.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Planet-Crossing Asteroid Search (PCAS)

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

Helin, E. F., Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. **OBJECTIVES:** A systematic search for planet-crossing asteroids is being conducted with the 0.46m and 1.2m Schmidt cameras at Palomar to increase the number of known asteroids, to establish improved estimates of their population and size distribution. Independent field pairs are photographed monthly; new objects are detected and followed to determine definitive orbits. When near-Earth asteroids are discovered, colleagues are informed so that physical observations may be attempted. These remote sensing techniques yield compositional information and suggest generic relationships. Populations of objects with different orbital characteristics are estimated from the observed numbers.

B. **PROGRESS IN 1986-1987:** From telescopic observations made at Palomar, 504 new asteroids were discovered and reported, with good orbits determined for 168. These discoveries range from Apollo 1986 PA, 2 Amors, 1986 LA and 1985 DO2 (discovered in late 1986) to Trojan 1986 VS7. Three other near-Earth asteroids were also discovered in conjunction with the PSS II in which PCAS played a strategic role. Other significant discoveries include 10 Mars-crossers, 7 Hungaries, 11 Phocaeas. Lost asteroid, 1026 Ingrid was recovered. Short period comet 1986d was also found. Observations of P/Halley recorded first evidence of unusual solar spike. Program results were derived primarily from 1.2m Schmidt PSS II plates, as the 0.46m Schmidt was being refurbished from June '86 through March '87. The International Near-Earth Asteroid Search (INAS) continues to produce numerous discoveries which are all published in the MPC's.

C. **PROPOSED WORK:** With the 0.46m Schmidt operational again, monthly observing runs have resumed. We will concentrate on increasing the number of faint PHO's from access to PSS II plates. INAS will complement these efforts by covering special preselected fields for expanded sky coverage. Augmentation is requested to cover 0.20 MY for special analysis and modelling studies utilizing data from observational work. (New Proposal to be submitted, June 1987)

D. **SUMMARY BIBLIOGRAPHY:** Discoveries and observed positions published in 14 International Astronomical Union Circulars, 61 Minor Planet Circulars, 5 papers published, 4 abstracts published, 3 papers in press, 10 oral presentations.

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Helin, E. F. (1985). New Earth-Crossing Asteroids, Apollo 1985 PA and Aten 1984 QA Found During International Near-Earth Asteroid Search, JPL Highlights, 1985.

Helin, E. F. (1987). Near-Earth Asteroid Searches: Status and Prospects, Proc. Intern. School of Physics, "Enrico Fermi", Varenna on Lake Como, Italy, Course XVII, August, 1985.

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Discovery and Astrometric Position Publications

International Astronomical Union Circulars:

1986d, IAU Circ. 4209, 4211, 4214, 4227; 1986LA, IAU Circ. 4228; 1986NA, IAU Circ. 4237; 1986PA, IAU Circ. 4242; 19861, IAU Circ. 4243; 1986RA, IAU Circ. 4252, 4256; 1986WA, IAU Circ. 4280; (1026) Ingrid, IAU Circ. 4281.

Minor Planet Circulars:

1986: MPC Nos. 10,369, 10,481–482, 10,489–491, 10,546, 10,550, 10,592, 11,011–012, 11,131–138, 11,404–407.
In 1987 MPC: 11488-490, 11596-601, 11612, 11616, 11706-711

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Stellar Observations with the Voyager EUV Objective Grating Spectrograph

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona

INVESTIGATOR'S NAME

Jay B. Holberg, Principal Investigators

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) During the periods of interplanetary cruise the Voyager ultraviolet spectrometers are used to provide unique and otherwise unobtainable observations in the extreme ultraviolet (EUV, 500-1200 Å) and the far ultraviolet (FUV, 912-1220 Å). These observations include the spectra of hot stellar sources, extra galactic sources, as well as the EUV and FUV sky background.

b) During the past year observations and studies of note include: 1) Voyager observations of several active galactic nuclei. These observations have resulted in the first FUV spectra of extragalactic sources. Objects so far detected include 3C273, Fairall 9 and Markarian 509. Results on several additional targets observed in early 1987 are not yet known. 2) Voyager 2 observations of the supernova in the Large Magellanic Cloud (SN 1987A) were obtained in late February and early March 1987. In a result consistent with IUE observations at longer wavelengths, no FUV flux was detected from the supernova during this period. However, important upper limits on emission shortward of 1200A were obtained. 3) An analysis was also completed on combined Voyager, IUE and ground. based observations of the hot He-rich degenerate KPD0005+5106. In this study estimates of the the photospheric N abundance were derived and the overall energy distribution was shown to be consistent with 80,000 K. This star is likely intermediate between the hotter PG1159 objects and the DO white dwarfs. 4) Finally, in a result closely related to Voyager astronomical observations, work was completed on a comparison of Voyager FUV stellar occultation observations of the Uranian rings at 1100A with ground-based occultation results at 2.2 microns. This work relied heavily on data techniques developed for the analysis of variable star observations obtained with Voyager.

c) Over the next 12 months we will continue to make Voyager observations of a wide variety of sources and plan to complete work in several areas. Important observations include several programs which are intended to provide *simultaneous* Voyager and IUE observations of active objects. These programs include: 1) Periodic (~ 8 weeks) observations of the supernova SN 1987A intended to look for the presence of highly ionized nebular emission lines expected to develop as the optical depth of the expanding remnant becomes lower. One such observation will be scheduled to coincide with a sounding rocket observation in the southern hemisphere. 2) FUV, UV, and ground-based coverage of the magnetic cataclysmic variable AM Her. 3) Additional Voyager and IUE observations of the active galactic nuclei; 3C273, Fairall 9, NGC 4151, PG1211+143 and Markarian 279. 4) An international campaign to obtain FUV, UV, and ground-based observation of short termed periodic variations in B stars. Work is also expected to begin on additional Voyager FUV and EUV observations of the sky background in particular, those observations obtained at low galactic latitude where a diffuse stellar-like spectrum is often present in the Voyager data. This signal may well represent the first spectra of starlight diffusly scattered from interstellar dust below 1200 Å.

d) See Summary Bibliography attached.

d) Summary Bibliography for 1986-1987

Canizzo, J. K., J. C. Wheeler and R. S. Polidan, Dwarf Nova Burst Asymmetry and the Physics of Accretion Disks, *Ap. J.*, **301**, 634, 1986.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Interiors of the Giant Planets

PERFORMING ORGANIZATION

Lunar & Planetary Lab, University of Arizona, Tucson, AZ 85721

INVESTIGATOR'S NAME

W.B. Hubbard

DESCRIPTION (a. *Brief statement on strategy of investigation;* b. *Progress and accomplishments of prior year;* c. *What will be accomplished this year, as well as how and why;* and d. *Summary bibliography*)

(a) This theoretical/observational project constrains interior structure of Jovian planets through observational data. We are now studying Neptune intensively via occultation observations in support of the 1989 Voyager encounter. The observations provide information on atmospheric structure and temperature profiles, and planetary oblateness and radius. We also continue to seek further data on the Neptune arc system discovered by this project. (b) We completed a detailed analysis of a large data set from the occultation by Neptune on 20 August 1985. Data from six different observatories were analyzed. From this we derived the oblateness e of Neptune at a pressure of 1 microbar (e = 0.021) and the equatorial radius a at the same pressure level (a = 25269 km). We derived a constraint on the methane abundance in Neptune's stratosphere: 0.6% at a pressure on the order of 0.3 mbar. The occultation data are also consistent with a temperature profile decreasing with pressure from 150 K at 1 microbar to 135 K at 0.4 mbar, with no measurable methane absorption. These results are consistent in temperature with models deduced from IR radiometry, but the stratospheric methane abundance is much lower than values inferred from the latter. We also analyzed the occultation data set to obtain new results on the wave spectrum of disturbances in Neptune's stratosphere, which are characterized by strong anisotropy. An extremely grazing Neptune occultation was observed on 4 May 1986. Although clouds were present, the unusual geometry permitted further confirmation of the anisotropy detected earlier. An unusual slow Uranus occultation was observed during the period 30 March - 2 April 1987. (c) We will continue to carry out multistation observations of favorable Neptune occultations. The next opportunity will be on 9 July 1987. This event will be observed from Chile and from the Tucson area. We will also make observations of other favorable planetary and asteroid occultations as opportunities occur. On the theoretical side, we will carry out a detailed synthesis of Neptune atmosphere models using the best available constraints from occultation data and from IR radiometry. (d) W. B. Hubbard: On the oblateness and rotation rate of Neptune's atmosphere. In Conference on the Jovian Atmospheres (M. Allison and L. D. Travis, eds.), NASA Conference Publ., 1986, p. 264.
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W. B. Hubbard: On the oblateness and rotation rate of Neptune's atmosphere. In Conference on the Jovian Atmospheres (M. Allison and L. D. Travis, eds.), NASA Conference Publ., 1986, p. 264.

E. Lellouch, W. B. Hubbard, B. Sicardy, F. Vilas, and P. Bouchet: The 1985 August 20 occultation by Neptune: The central flash determination of Neptune's oblateness and methane stratospheric mixing ratio. Nature 324, 227, 1986.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Studies of Extended Planetary Atmospheres

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Donald M. Hunten, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Spectroscopic observations of gases and plasmas in the Jupiter system, and related phenomena such as the recently-discovered sodium atmosphere of Mercury. Construction of four data systems for an ongoing program of planetary and asteroid occultations.

b. Cunningham has completed analysis and modeling of spectra taken from specific regions of Jupiter, and her thesis is about half written. The hydrogen ortho/para ratio near 1 bar is close to equilibrium with the local temperature. The optical thickness of the ammonia cloud increases from about 3 in the morning to 6 at sunset. This effect seems to be due to the combination of internal heat flow and a convective region heated at the top, giving strong convection at night and none during the day.

Schneider has analyzed most of the data from the eclipses of other satellites by Io's sodium atmosphere, and a paper has been submitted to Science. The data extend to nearly 10 Io radii and nicely match the densities in the outer regions obtained from the intensity scattered in the D lines. A fuller analysis is proceeding and writing of a thesis is under way.

Several more runs have been obtained on the Mercury sodium lines, and it is clear that our equipment is extremely well suited to this kind of work. We have also been able to observe one of the potassium lines.

Four new occultation data systems have been built, to replace the obsolete ones constructed in 1978. They have already been used for Pluto-Charon occultations and a Uranus ring event.

c. Further observations of the Mercury sodium and potassium emissions will be carefully planned to monitor spatial and temporal variations and seeing quality. This will be a Ph.D. project for A. Tyler, who will also be modeling the gas-surface interaction.

Further work on sodium near Io and on the plasma and neutral torus is planned, in collaboration with R.A. Brown and N. Schneider.

The comprehensive spectroscopic program for Jupiter will be extended to Saturn.

Occultations will be observed as opportunities arise. Relatively frequent events involving the rings of Uranus and arcs of Neptune are of particular interest.

d. Schneider, Wells, Hunten & Trafton (1987), Eclipse measurements of Io's sodium atmosphere, submitted to Science. Cunningham & Hunten (1987), H_2 spectroscopy and a diurnally changing cloud on Jupiter, submitted to Icarus. DPS papers by Schneider, Cunningham, and Tyler.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radiative Transfer in Planetary Atmospheres

PERFORMING ORGANIZATION

Department of Physics and Astronomy
University of Massachusetts
Amherst, MA 01003

INVESTIGATOR'S NAME

William M. Irvine

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Theoretical techniques and observations at millimeter wavelengths are combined to study the atmospheres of planets and comets, planetary and satellite regoliths, and planetary rings.

b. The research effort during the past year was concentrated on observations and interpretation obtained during the apparition of comet P/Halley. A total of 56 individual observing sessions at the wavelength of the J=1-0 rotational transition of the HCN molecule were carried out at the University of Massachusetts 14 m antenna. This is the first time that a cometary parent molecule has been so extensively observed. The HCN production rate is well correlated with the total visual magnitude of the comet, although HCN accounts for only about one part in a thousand of the total gas production. The high spectral resolution of the millimeter wavelength observations allows the outflow velocity of gas in the cometary coma to be determined. A complementary series of observations of emission by the OH radical in the coma were obtained with the 43 m antenna of the NRAO. The OH parent production rate derived with the aid of a new radio model (1986a) removes some of the traditional discrepancy between radio and ultraviolet production rates. The data are moreover well fit by an inverse square law for the range in heliocentric distances observed. The Greenstein Effect on the mean OH velocity is clearly apparent. Observations at the wavelengths of both the OH and the HCN transitions have been initiated on comet Wilson, in an effort to compare this new comet with periodic comet Halley.

c. Observations of the ground-state OH lambda doublet and the J=1-0 rotational transition of HCN will be continued for comet Wilson. Reduction and interpretation of the results obtained for comet Halley will be continued. In particular, detailed comparison will be made between the HCN brightness and the corresponding intensity of CN emission obtained from optical photometry. In addition, a model is being developed for the excitation of HCN in the coma which will include the possibility of time dependent outbursts and anomalies in the ratio of the hyperfine lines. A model for the OH emission is being constructed using Monte Carlo techniques to account for the distribution of OH velocities following the dissociation of its parent. The model can easily include the OH Greenstein Effect, anisotropic outgassing from the nucleus, and the effects of beam resolution of the coma by the antenna used for the observations. The high spectral resolution obtained warrants such detailed examiation of the line profiles.

d. During the past year ten articles have been published in scientific journals or conference proceedings, and another ten have appeared as abstracts or IAU circulars.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Laboratory Simulation of the Surface of Halley's Comet

PERFORMING ORGANIZATION

Chemistry Department
University of California
Davis, CA 95616

INVESTIGATOR'S NAME

William M. Jackson

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

The strategy of this investigation is to use model polymer compounds and laser induced fluorescence to show whether vacuum UV radiation can directly desorb cometary radicals from the surface of polymeric materials. The vacuum UV source will be Raman shifted laser light at a low enough intensity so that multiphoton phenomena can be ignored. Radicals that are desorbed from the surface will be detected by laser induced fluorescence. This is the most sensitive technique for monitoring such a species.

This is the first year of the grant. We expect to design the observation cell and to show that we can detect CN radicals with this cell. Our initial studies will be performed with HCN polymers as well as cyanogen polymers.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Ground Based Infrared Astronomy

PERFORMING ORGANIZATION

Planetary Systems Branch
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME

D. E. Jennings, Principal Investigators

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Infrared spectroscopic instrumentation has been developed for ground-based measurements of astrophysical objects in the intermediate infrared. A conventional Michelson interferometer is limited for astronomical applications in the intermediate infrared by quantum noise fluctuations in the radiation from the source and/or background incident on the detector, and the multiplex advantage is no longer available. One feasible approach to recovering the multiplex advantage is post-dispersion. The infrared signal, after passing through telescope and interferometer, is dispersed by a low resolution grating spectrometer onto an array of detectors. The feasibility of the post-dispersion system has been demonstrated with observations of astrophysical objects in the 5 and 10 m atmospheric "windows" from ground-based telescopes. Ground-based observations will be made during FY87 with the post-dispersion system at Kitt Peak using the FTS at the 4-meter telescope, and McMath telescope.

b) During FY87 the postdisperser was used at the Kitt Peak 4-meter telescope and McMath telescope with facility Fourier transform spectrometers. Jupiter, Saturn, Mars, and Venus were observed. On Jupiter, the resolution at 12 microns was 0.01 cm^{-1}, considerably higher than had been achieved previously. The spectrum contains Jovian ethane emission and ammonia absorption is being analyzed. The linear detector array has been tested.

c) Proposals will be submitted for FY88 to observe Jupiter, Saturn, Mars and Venus with the 4-meter and McMath FTS' using the Goddard postdisperser. Manuscripts are being prepared.

d) Publications

"A Cryogenic Grating Postdisperser for Astronomical Observations using Fourier Transform Spectrometers," G. Wiedemann, D. Jennings, V. Kunde, G. Lamb, H. Moseley, and R. Hanel, in preparation.

"Detection of 12 micron MgI and OH Lines in Stellar Spectra," D. Jennings, D. Deming, G. Wiedemann, J. J. Keady, Ap. J., 310, L39(1986).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
Optical Investigation of Comet Halley

PERFORMING ORGANIZATION
Massachusetts Institute of Technology, Room 54-418
Department of Earth, Atmospheric and Planetary Sciences
Cambridge, MA. 02139.

INVESTIGATOR'S NAME
David C. Jewitt

DESCRIPTION *(a. Brief statement on strategy of investigation, b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a). We are using state of the art optical detectors (mostly CCDs) to determine the properties of comet P/Halley. The observations are taken at high spatial, spectral and temporal resolution. Our objective is to determine and interpret a self-consistent set of ground-based observations of this comet in light of the detailed nucleus properties found from the spacecraft encounters. As a natural by-product of the present study, work has been done to elucidate the statistical spectral and photometric properties of other comets.

(b). (i). Photometric determination of the (unexpectedly early) onset of particulate mass loss from the nucleus (R = 6 AU), and comparison with a physical model of the nucleus (ref #1).
(ii). A study of the wavelength dependence of the scattering cross section of solid grains in the comae of comets. The measured dependence is consistent with the mean grain radius $a \geq 1$ μm. Significant differences among the continua of comets suggest intrinsic differences in the grain populations (ref #2, #4).
(iii). A measurement of the scattering angle dependence of the continuum cross section of P/Halley obtained at the time of minimum phase angle in November 1985 (ref #3, #6). No opposition effect is seen; only a linear phase coefficient is present. Comparison with scattering from other Solar System bodies is attempted.
(iv). The surface brightness profiles of a dozen comets have been measured at continuum optical wavelengths. The profiles indicate substantial departures from the canonical $1/r$ surface brightness law, but are generally consistent with a Monte Carlo model which incorporates solar radiation pressure (Ref #5).

(c). In the next year of funding, we will (i). complete our CCD lightcurve of P/Halley. The lightcurve constitutes a unique and unbiassed record of activity in the comet. A model of the activity is being developed. (ii). Study the grain coma profile of P/Halley for evidence of surface brightness waves driven by the variable nucleus mass loss rate. The waves will provide a direct measure of the speed of ejected grains as a function of R, allowing us to test Bobrovnikoff's relation. (iii). Monitor the decline of the coma as the comet recedes to R > 6 AU. Initial observations indicate an intriguing asymmetry in the decline as compared to the rise of the coma in 1985. (iv). Attempt a photometric determination of the rotation state of the nucleus, once the coma has faded. (v). Analyse our set of ≈ 100 plasma images taken at the CTIO and KPNO Schmidts in the last 2 years.

(d). Bibliography

(1). K.J. Meech, D.C. Jewitt and G.R. Ricker (1986), *Icarus* **66**, 561 - 574.
(2). D.C. Jewitt and K. J. Meech (1986), *Ap. J.*, **310**, 937 - 952.
(3). K. J. Meech and D. C. Jewitt (1986), 20th ESLAB Symposium, ESA SP-250, p553, Vol I.
(4). D. C. Jewitt and K. J. Meech (1986), 20th ESLAB Symposium, ESA SP-250, p47, Vol II.
(5). D. C. Jewitt and K. J. Meech (1987), *Ap. J.* June 15 issue, in press.
(6). K. J. Meech and D. C. Jewitt (1987), *Astron. & Astrophys*, in press.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Observations of Outer Planet Satellites

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

T. V. Johnson, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. OBJECTIVE: This task supports IR observations of the outer planet satellites. These data provide vital information about the thermophysical properties of satellite surfaces, including internal heat sources for Io. Observations include both broad and narrow band measurements in the 2 to 20 μm spectral range. Most observations are carried out at the IRTF facility on Mauna Kea. Types of observation and target priority are determined to make maximum use of existing data from Voyager and other missions, support on-going and planned missions such as Galileo, and to develop techniques and data for planning new missions and instrumentation.

B. PROGRESS: The program in the last year has aimed at obtaining longitude coverage on Io to establish stability of hot spot patterns previously reported. Several runs produced the most complete data set for an apparition since we started the program in 1983; unfortunately bad weather limited coverage of key longitude ranges containing the largest known hot spot Loki. Among the preliminary results (reported at the 1985 DPS meeting) is the observation of a distinct change in 4.8 μm emission levels from the same longitudes during the summer of 1985; little or no change was observed in simultaneous 8.7 and 10 μm data, suggesting a small, relatively hot (~400K+) spot as the possible origin of this variation. Limited data were obtained for one run during the 1986 apparition and are being analysed. We are collaborating with J. Goguen (NRC RRA) to finish reduction of mutual event data, which have already improved ephemeris information for the satellites. The data appear to place significant limits on the characteristics of any leading side hot spots. Our earlier data were used in two published analysis papers concerning correlations of hot and dark regions and models for the occulation data at several wavelengths.

C. PROPOSED WORK: During 1987 we plan a series of 3 to 4 observing sessions. Emphasis will be on studying the suspected variability of the high temperature component(s) suggested by last year's data and on obtaining longitude coverage constraining the hot spots in the Loki region.

D. BIBLIOGRAPHY: McEwen, A.S. et al., Volcanic Hotspots on Io: Correlation with low-albedo calderas, JGR, 90, 12345-12379, 1985. McEwen, A.S. et al., Calculated Occultation Profiles of Io and the Hot Sports, GRL, 13, 201-204, 1986. Three papers in preparation.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Goldstone Solar System Radar Astronomy

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasaden, CA 91109

INVESTIGATOR'S NAME

R. F. Jurgens, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. OBJECTIVES: This work unit supports the planning, data processing, preliminary analysis, and computer facility support for ground based radar observations of planets, moons, asteroids, comets and planetary rings. Raw data signal voltage samples from receiving stations is provided by other work units funded by OSTDS. Data acquisition is accomplished through the unique S-Band and X-Band transmit-receive capability of the Deep Space network. These processed data provide radar brightness and altitude maps, altimetry profiles, surface scattering and polarization characteristics, spin vectors, physical shapes, and ephemeris corrections. This information complements and enhances other planetary data obtained by flight projects and is used for planning and design of new space missions.

B. PROGRESS (FY'87): Most of the effort this FY was directed at obtaining new high resolution imaging data of Venus and completing the computer software necessary to reduce these data to images. The entire software set for reducing the image sets through 1982 is now complete, and data reduction of the backlog of data is in progress. Modifications of the software required to reduce the 1985-86 data are also expected to be complete this FY so that at least a few images from this set can be processed. All of the tristatic radar data from 1977 through 1982 should be converted from 7 track to 9 track high density tape, and a data base describing the data will be available to the science community. Considerable effort has been directed toward supporting new observations of Mars, Titan, the Saturn rings, the moon and two asteroids. A complete set of quick-look data verification programs have been completed for use with radar experiments and are currently resident at DSS-14 and at JPL.

C. PROPOSED WORK (FY'88): Most of our work will be directed at reducing the backlog of radar data that has accumulated during the 1982-1985 facilities and software upgrades. Nearly all older data should be completed and released for distribution to outside users. Conversion of computer software necessary to reduce the new data products will continue into this period. New initiatives include analysis of the Goldstone-VLA Titan data, development of software tools needed to support rapid acquisition of newly discovered near earth asteroids and comets, and the development of better realtime algorithms for data acquisition and verification. During this period, the 70 meter upgrade of DSS-14 will begin. New SIRDs and NSPs are required as well during this FY.

D. BIBLIOGRAPHY: Clark, P. E., Jurgens, R. F., and Kobrick, M.,"Characterization of Venus Subdued Terrains with Ground-Based Radar-Derived Data," LPI XVIII, 179, March 1987, Houston TX.; Slade, M. A., Zohar, S., and Jurgens, R. F., "Venus: Improved Spin Vector from Goldstone Radar Observations," LPI XVIII, 932-933, ibid.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radar Imaging of Venus

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

R. F. Jurgens, Principal Investigators

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. OBJECTIVES: The objective of this work unit is to provide new high resolution images of portions of Venus. These images will then be analyzed here and by other investigators to provide the following scientific results needed for specific mission goals: 1. accurate determination of the spin state; 2. location and measurement of benchmarks needed to establish an accurate coordinate frame over an extensive longitude grid; 3. understanding the geological processes active on Venus. Data are acquired using the triple-interferometer of the Goldstone Solar System Radar (GSSR) under separate funding OSTDS. Raw data products are reduced to image products through an extensive set of software developed under the GSSR astronomy work unit.

B. PROGRESS (FY'87): New data were acquired during the inferior conjunction Venus of October 1986. These observations were made with the highest resolution ever using ground based facilities and should yield several images with with resolution approaching one km squared. Twelve successful days of observations were obtained with varying resolution. New quick-look software was developed to verify that the data acquisiton system was giving good data. Interferometric fringes have been obtained on the highest resolution data indicating there is no physically limiting process degrading the phase integraty of the system. A new data editing program has been completed and intial work is progressing of the software modifications needed to product the first two images this FY.

C. PROPOSED WORK (FY'88): Work will continue on the reduction of the twelve days of data into images of reflectivity and altimetry. Some special software will have to be developed to reduce the data from days when only two stations were operating. As the funding guideline is substantially below the proposed funding for this project, we do not expect to be able to reduce more than half of the current image set this FY.

D. BIBLIOGRAPHY: As this is a relatively new task, no results form the new data set will be reported this FY, however, some associated work with the Magellan project yielded a new and more accurate measurement of the pole of Venus: Slade, M. A., Zohar, S., and Jurgens, R. F.,"Venus: Improved Spin Vector from Goldstone Radar Observations", LPI XVIII, pp. 932, Houson, TX, 1987. The techniques used for data processing are described by: Jurgens, R. F., Goldstein, R. M., Rumsey, H. R., and Green, R. R., "Images of Venus by Three-Station Radar Interferometry - 1977 Results," JGR, 85, 8282-8294, 1980.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Submillimeter Spectroscopy

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

M. J. Klein, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Develop a comprehensive observational strategy for the detection and measurement of molecular lines in the millimeter and submillimeter spectra of planetary atmospheres and comets. A primary objective is to develop a sound observational strategy and the associated analytical capability to begin observations from the Caltech Submillimeter Observatory (CSO) on Mauna Kea Hawaii.

(b) Halley: (NH_3) Set upper limit to production rate from 13mm observations with DSN 64-m in Australia. (H_2O) Set upper limit to production rate from 1.6mm observations from NASA KAO flight in May 1986.
Uranus: Paper interpreting microwave spectrum submitted to Icarus; began work on model fitting and analyses of low frequency radio emission from Voyager 2 PRA experiment.
Jupiter: Reported correlation study of synchrotron flux vs solar wind parameteres (Univ of Iowa Conference Sep 86). Continued 13cm Jupiter Patrol at Goldstone.
Venus: Collaborated with Paul Steffes (Georgia Tech) to search for H_2SO_4 absorption in microwave spectrum using NRAO 140ft radio telescope.

(c) Develop plans for CSO Planetary observations. Publish paper on Venus H_2SO_4 results. Participate in International Jupiter Watch Conference (paper with I. dePater) and continue Jupiter patrol observations using DSN. Increase observations for IGW throughout week of Jupiter opposition (Oct. 87). Publish paper on DSN & KAO Halley observations.

(d) Manietti, Green, Six & Gulkis JGR, 92, pp27-38 1987. Gulkis,S, "Planetary Radio Astronomy" Encycl. Phys. Sci & Tech., Academic Press, pp633-653, 1987.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

INFRARED SPECTROSCOPY OF JUPITER AND SATURN

PERFORMING ORGANIZATION

Research Foundation
State University of New York
Stony Brook, New York 11794

INVESTIGATOR'S NAME

Roger Knacke

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

The strategy of the investigation is the study of the atmospheres of Jupiter and Saturn with infrared spectroscopy. We have concentrated on the 5 micron region in recent years, and placed major emphasis on carbon monoxide as a tracer of atmospheric processes.

In the prior year, analysis of the Jovian CO studies was completed and submitted for publication. The line profiles indicate that the line forming region is at a pressure of 2 to 9 bars and CO is present at a mole fraction of $1.6 \pm 0.3 \times 10^{-9}$. CO in the troposphere clearly favors models with rapid vertical mixing as the source of CO. The observed CO mole fraction shows that the global oxygen abundance below the cloud forming regions is near the solar value, and not enormously depleted. Thus the low H_2O abundance must be a condensation or dynamic effect rather than indicative of low oxygen abundance.

We obtained new data pertaining to the issue of the germane abundance in Jupiter and Saturn. Absorption occurs at expected wavelength positions of several germane bands in Saturn but not at the Q branch. Synthetic atmosphere calculations which incorporate scattering are in progress to try to resolve the difficulties in understanding this complex region of Saturn's atmosphere. Preliminary results indicate that the absorptions are indeed germane. If this result stands, it will be strong evidence for rapid vertical mixing in Saturn's atmosphere.

In the present year we propose to complete the modeling of the Saturn spectra. K. Noll will complete his Ph.D. thesis based on this work. We also plan an observing run in September to pursue the issue of the origin of CO in Saturn.

Bibliography (1986-87)

Noll, K.S., Knacke, R.F., Tokunaga, A.T., Lacy, J.H., Beck, S., and Serabyn, S: The abundances of Ethane and Acetylene in the Atmospheres of Jupiter and Saturn. Icarus, 65, 257-263 (1986).

Noll, K.S., Knacke, R.F., Geballe, T.R., and Tokunaga, A.T.: Detection of Carbon Monoxide in Saturn. Ap. J., 309, L91-L94 (1986).

Noll, K.S., Knacke, R.F., Geballe, T.R., and Tokunaga, A.T.: The Origin and Vertical Distribution of Carbon Monoxide in Jupiter. Ap. J., submitted.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Advanced Infrared Astronomy

PERFORMING ORGANIZATION

Planetary Systems Branch
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME

T. Kostiuk/D. Deming/M. Mumma

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) This task supports the application of infrared heterodyne and Fourier transform spectroscopy to ultra-high resolution studies of molecular constituents of planetary atmospheres and cometary comae. High spectral and spatial resolutions are especially useful for detection and study of localized, non-thermal phenomena in low temperature and low density regions, for detection of trace constituents and for measurement of winds and dynamical phenomena such as thermal tides.

b) In FY87 the Lamb-dip absorption cell was used on two occasions with the heterodyne spectrometer at the IRTF on Mauna Kea. Extensive, high quality, data were obtained on winds at 110 km altitude on Venus. The heterodyne spectrometer was also used to search for 9 micron absorption due to Ozone on Mars. Analysis of heterodyne data on the variability of Jovian ethane emission was completed and submitted for publication. Data on the infrared fluorescent emission from water vapor in Comet Halley was analyzed to yield the water production rate, the expansion velocity in the coma, and the ortho-to-para ratio for water. A large number of publications resulted. Observations of fluorescent water vapor emission from Comet Wilson were scheduled on the KAO.

c) In FY88 the analysis of the Venus wind data will be completed, and submitted for publication. During the 1988 opposition of Mars, data will be obtained using the Lamb-dip stabilized heterodyne system to measure Martian wind velocities near 70 km altitude. The data on water vapor emission from Comet Wilson will be analyzed and published. Further heterodyne observations relevant to Jovian stratospheric photochemistry will require a longer wavelength laser local oscillator. Accordingly, such a local oscillator will be developed during FY88. Also in FY88, a preliminary search for p-mode oscillations of Jupiter will be conducted.

d) "Polar warming in the Middle Atmosphere of Mars", D. Deming et al., Icarus, 66, 366, 1986. "Detection of Water Vapor in Halley's Comet", M. J. Mumma et al., Science, 232, 1523, 1986. "Velocity-Resolved Observations of Water Vapor in Comet Halley", H. P. Larson et al., Ap. J. Lett., 309, L85, 1986. "Post-Perihelion Observations of Water in Comet Halley," H. A. Weaver et al., Nature, 324, 441, 1986. "The Ortho/Para Ratio of Water Vapor in Comet Halley", H. P. Larson et al., Proc. of the Heidelberg Symposium, 1986. "Spectroscopy of Comets: An Infrared Perspective", H. P. Larson et al., Proc. of the Heidelberg Symposium, 1986. "Airborne Infrared Investigations of Water in the Coma of Halley's Comet", H. A. Weaver et al., Proc. of the Heidelberg Symposium, 1986.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Cometary Spectroscopy and Imaging

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Stephen Larson, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) The objectives of this on-going observational program are to obtain data on the spectroscopic and morphological characteristics of comets over a wide range of heliocentric distances. Statistical analysis of such data may suggest or constrain models of cometary formation environments and evolution. Long slit spectra and direct images of all observable comets are obtained on a monthly basis (weather permitting) with a CCD spectrograph/camera. Scale lengths of the principal emissions of OH, NH, CN, C3, C2, NH2 and OI in different comets can be compared. The direct images are used for studies of dust anisotropy which can provide data on the spin vector and to aid in the interpretation of spectral line profiles, and, with good time resolution, are used to look for rotationally modulated light curves. If there are gaps between comets, the CCD is used in the coronagraphic mode to investigate potentially visible circumstellar disks.

b) Observations - Direct images and/or spectra of Comets Halley (1982i), Wilson (1986l), Klemola (1987i), Sorrells (1986n), Shoemaker (1987o), Schwassmann-Wachmann 1 and 2, Torres (1987j) and Urata Niijima (1986o) were obtained over the past year. P/Halley was observed systematically for several weeks in early 1987 in an attempt to identify a periodic lightcurve. Coronagraphic images and spectra of the Beta Pictoris disk and SN1987a were obtained from the Cerro Tololo and Las Campanas Observatories, and we can now set limits on the optical brightness of suspected circumstellar discs of 12 stars.

Instrumentation - In conjunction with Photometrics Inc., we tested several phosphor coatings to improve the blue and UV sensitivity of our CCD. Coronene gave the best results for our unbacked RCA CCD and reduced fringing effects dramatically. The 12 position filter wheel was modified for control by the CCD computer, and a rotating polaroid has been installed and calibrated. The CCD was adapted for digitizing photographs as a rapid alternative to scanning the backlog of microchannel plate spectra.

Analysis - Hundreds of our CCD images of P/Halley from the 1985-86 apparition were reduced and enhanced to show jet structure which closely mimicked those on 1910. Photometry from the March and April 1986 CCD images is consistent with published light curves and shows that brightness peaks correlate with new jet production. The observed

expansion velocity and curvature of the jets still indicate a 2.2 day rotation component. We applied our jet enhancement algorithm to VEGA 2 images to help determine the three dimensional distribution of jets and help define their emission locations on the nucleus surface.

c) Besides the usual monthly observations, we plan to make extensive observations of P/Tempel 2 in support of CRAF. We will continue to investigate means of improving the blue sensitivity of our CCD and improving observing efficiency. We hope to finish reduction of the P/Halley and P/Giacobini-Zinner images and analyze the many Halley jet features and light curve to provide some insight to the spin vector problem. We hope to correlate the groundbased observations of jets with those in Vega 1 and 2.

d)Publications:

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Observations of Solar System Objects

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Larry A. Lebofsky

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) This program is a continuing effort to study the near (reflected) to thermal flux from asteroids and other airless bodies using groundbased telescopes. The goal of the observations is to investigate the mineralogy and thermophysical properties of these bodies and to support present and potential future missions such as Galileo, CRAF and IRAS.

b) During the past year, work was completed on the publication of the IRAS catalog of asteroids. Also, in a parallel effort, we completed work on the "Refined standard thermal model" for the reduction of IRAS and groundbased observations. Much effort has gone recently into efforts to understand the Pluto/Charon system. Two efforts, one at the U. of Arizona and one with the U. of Hawaii have established the presence of water ice on the surface of Charon. We are also involved with groups in Tucson and at JPL in the analysis of IRAS observation of Pluto and Charon.

c) With much of the IRAS and Pluto efforts out of the way, the goal for the next year is to complete work on thermal IR observations of asteroids. This will include: 1) publication of a thermophysical model for asteroids similar to the refined standard thermal model; 2) a new effort to study asteroid shapes from reflected and thermal observations. This will be the analysis of data recently taken that proves that the lightcurves for 532 Herculina and 45 Eugenia are due primarily to shape rather than albedo variations across the surface.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Outer Planet Studies (NSG-7499)

PERFORMING ORGANIZATION

Lowell Observatory

INVESTIGATOR'S NAME

Barry L. Lutz

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) This work centers on observational studies of the composition, structure, and variability of the atmospheres of the outer planets and of Titan and the investigation of the problems associated with the fundamental calibration of these data, all of which are essential to providing ground-truth support of the *Voyager* and *Galileo* spacecraft missions. The tasks also focus on the application of these observations of the current state of the solar system to the study of its origin and evolution. A modest laboratory effort designed to provide the data needed to carry out these observational programs is also maintained.

b) We have completed and published our spectrophotometric study of Titan, determining its absolute flux and geometric albedo. We have continued our spectrophotometry of Neptune and have extended the database for temporal study of Uranus. We have nearly completed a new solar flux calibration putting our planetary measurements on a self-consistent stellar flux scale and eliminating discrepancies due to inconsistencies in absolute calibrations of the Sun and standard stars. We have also completed our studies of CH_3D in the atmospheres of Uranus and Titan, one of which has been published, the second of which has been submitted. We have nearly completed a similar study of Saturn. We have used these observational results to investigate the abundance and elemental distribution of deuterium in the solar system and its relationship to the primordial concentration of deuterium and have published four papers regarding our conclusions. We began a search of HDO in the Martian atmosphere and for DCl on Venus. The Mars observations yielded the first detection of deuterium on that planet. We have continued our study of ^{13}C in the atmospheres of Jupiter and Saturn. Some progress was obtained in our laboratory analysis of CH_3D lines broadened by N_2.

c) We will extend our spectrophotometry of Jupiter in support of groundbased imaging studies of the temporal and spatial aspects of the vertical structure of the Jovian atmosphere as fundamental baseline data for *Galileo*. We will complete and publish our new calibration of the solar spectral irradiance based on the stellar flux scale for Vega, and we will continue our modest program of spectrophotometry of solar-type stars to calibrate and define appropriate "solar analogues." We plan to complete and publish our spectrophotometric observations of Neptune and its geometric albedo, extend our study of temporal variations in the atmosphere, and provide additional spectrophotometry close to the *Voyager* encounter in 1989 in support of this spacecraft mission. We plan to model our temporal data on Uranus to aid in deconvolving the observed spectral changes due to intrinsic time-dependent variation in its atmosphere from those due to changing aspect. Our observations of CH_3D in the outer solar system will be completed with a search for it in the atmosphere of Neptune and with publication of our analysis of this molecule in the atmosphere of Saturn. At the same time we will finalize and publish our analysis and interpretation of HDO in the atmosphere of Mars, and pursue our study of DCl on Venus. Similarly, we will continue our efforts in determining the $^{12}C/^{13}C$ ratio in the outer solar system by publishing our results for Saturn and completing our analysis of the data for Jupiter. Our laboratory efforts will remain a low priority, determined by our own observational needs.

d) Bibliography.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Asteroid Team

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

D. L. Matson, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. OBJECTIVES: The purpose of this task is to support asteroid research and the operation of an Asteroid Team within the Earth and Space Sciences Division at JPL. The Asteroid Team carries out original research on asteroids in order to discover, better characterize and define asteroid properties. This information is needed for the planning and design of NASA asteroid flyby and rendezvous missions. The Asteroid Team also provides scientific and technical advice to NASA and JPL on asteroid related programs.

B. PROGRESS: 1) Work on asteroid classification continued and the discovery of two Earth-approaching "M" asteroids last year was published. (The M-class is rare and these are the first found among the near-Earth asteroids to have the spectral albedo characteristic of this class. The derived diameters are about 2 km for both objects.) 2) In the asteroid photometry program we obtained N or Q photometry for more than 50 asteroids, including the two M-earth-crossers. 3) We have initiated a new program to follow-up on IRAS asteroids at the IRTF. 4) Compositional analysis of infrared spectra (0.8 to 2.6 μm) of 60 asteroids was started. 5) This task supported D. Matson's travel for and participation in the NASA Planetary Astronomy Management and Operations Working Group. 6) This task is supporting the preparation of manuscripts for the publications of the IRAS Asteroid and Comet Catalog.

C. PROPOSED WORK: Over the next year the work on asteroid classification and composition will continue with the analysis of the 60 reduced infrared spectra which we now have at hand. The radiometry program will continue with the reduction of the N and Q bandpass data for the 57 asteroid in order to obtain albedos and diameters. This year the emphasis will shift to IRAS follow-up observations; which includes objects not observed by IRAS and objects with poor or peculiar IRAS data. As in previous years we plan to give top priority to any opportunites for observing near-Earth asteroids and the support (through radiometric lightcurve observations from the IRTF) of any stellar occultations by asteroids for which occultation observation expeditions are fielded. Support of preparing of IRAS data for publication and of D. Matson for his participation in the NASA Planetary Astronomy Management and Operations Working Group will continue.

D. SUMMARY BIBLIOGRAPHY: Matson, D. L. (1986), Ground-based Observations of Io, in Proceedings of the Solid Bodies of the Outer Solar System, ESA SP-242; Lebofsky, L. A. et al. (1986), A Refined "Standard" Thermal Model for Asteroid Based on Observations of 1 Ceres and 2 Pallas, Icarus 68, 239-251; Tedesco, E. F. and Gradie, J. (1987), Discovery of M Class Objects Among the Near-Earth Asteroid Population, Astron. J. 93. 738.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Research & Planetary Astronomy

PERFORMING ORGANIZATION

Hawaii Institute of Geophysics
University of Hawaii

INVESTIGATOR'S NAME

Thomas B. McCord

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Continue long-term program designed to study the composition, structure and processes operating on the surfaces of solar system objects using the Mauna Kea Observatory and techniques and modern instrumentation mostly developed internally. Reflectance spectroscopy and multispectral imaging in the spectral region, 0.3-5.0μm, are the major techniques to be used although thermal radiometery and special imaging techniques are used for some programs. Of major importance is the active involvement of graduate students and young scientists in the program in order to develop new expertise as well as new knowledge and techniques for the NASA Solar System Exploration Program.

b) Fifty-four full nights of telescope time at Mauna Kea were allocated for this program last year. Program results included: (1) Mars: 0.7μm and 2.2-4.2μm observations of Tharsis Plateau, South Polar Cap, Syrtis Major and Elysium; (2) Moon: 2.2-3.2 μm observation of a proposed comet impact site in a search for water; IR imaging of large areas using newly implemented InSb linescan camera; 0.7-2.5μm observations of volcanic regions show no evidence of an ultramafic mantle component, a result applicable to Mercury; (3) 10 and 20 μm observations of faint asteroids including 1986 DA and 1986 EB which are the first two M-class objects discovered among the planet crossing population; (4) a survey of eight asteroids in search of satellites and dust shells; (5) color imaging of the Beta Pictoris circumstellar disk; (6) a search for "brown" dwarf companions to nearby stars; (7) instrument development of the imaging spectrometer using 2-D IR detectors and the stellar coronograph; (8) development of IR imaging capability using InSb line arrays.

c) Major focal points for this year include: (1) high resolution spectral reflectance observations of selected areas of the moon in our continuing program and IR imaging of large areas; (2) spectral (0.7-5.0 μm) observations of Mars in support of MOM and the Galilean satellites in support of Galileo; (3) spectral relectance measurements of faint and earth approaching asteroids; (4) observations of circumstellar disks; (5) continuation of our search for "brown" dwarf companions.

d) Five papers published; two papers in press; one paper submitted; six abstracts published.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
Astrometric Observations of Comets and Asteroids and Subsequent Orbital Investigations

PERFORMING ORGANIZATION

Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge MA 02138

INVESTIGATOR'S NAME

Principal Investigator: R. E. McCrosky
Co-investigator: B. G. Marsden

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Astrometric observations are made of comets and minor planets for use in orbit computations. Direct photographic observations are made with the 1.5-m reflector at the Oak Ridge Observatory. The emphasis is on faint or unusual objects, but attention is also given to newly discovered objects.

(b) During the past year 653 positional measurements were obtained, 78 of them referring to comets. Of special interest were observations of 11 new comets discovered during the year and continuing coverage of P/Halley. 55 minor planets were given permanent numbers entirely as a result of our observations. Several thousand preliminary and improved orbit computations were made. Among the many hundred minor-planet identifications found was (473) Nolli, which had been lost since 1901.

(c) Observations are expected to continue much as usual as occasion demands. Orbit computations, ranging from preliminary computations for new objects, through rigorous least-squares differential corrections, including considered of planetary perturbations and (for comets) nongravitational effects, will also be made as appropriate. In response to a special augmentation of this grant we intend to improve the situation with regard to receipt by astronomers around the world of astronomical information in urgent need of rapid dissemination, particularly with regard to supernovae and specifically about SN 1987A in the LMC. An alternate MicroVAX computer is to be established with full network capability and in the hope that information can be accessed by and relayed to and from all potential users at all times.

(d) Observations have been published during the past year on 49 Minor Planet Circulars and 7 IAU Circulars. Orbits are on 165 MPCs and 46 IAUCs.

Astrometric Observations of Comets and Asteroids and Subsequent Orbital Investigations

Publications:

As far as observations are concerned, the MPCs have been declared a refereed journal, and observations from Oak Ridge plates are contained on MPC Nos. 10676-10677, 10699, 10794-10795, 10815-10816, 10891, 10893, 10909-10910, 10997-10999, 11015-11016, 11111, 11139-11140, 11209, 11228-11229; 11277-11278, 11329-11330, 11379-11380, 11414-11415, 11468, 11496-11497, 11564-11567, 11604-11605, 11683-11686, 11714-11716, 11779 and 11822-11823.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

MINOR PLANETS: INTERRELATIONSHIPS WITHIN THE SOLAR SYSTEM BASED ON SPECTRAL REFLECTANCE

PERFORMING ORGANIZATION

Astronomy Program, Department of Physics and Astronomy
University of Maryland, College Park, MD 20742-4111

INVESTIGATOR'S NAME

Lucy-Ann McFadden

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Strategy - Wisdom discovered a mechanism which results in the formation of the 3:1 Kirkwood Gap. It is possible that collisional fragments from asteroids near the 3:1 Kirkwood Gap are subjected to this same mechanism and perturbed into Earth-crossing orbit. Wetherill derives the orbital elements of ordinary chondrite meteorites based on time of day fall statistics and determines orbits with semi-major axis = 2.5 AU, the location of the 3:1 Kirkwood gap. An enigma in this scenario is that there are very few observed asteroids with the spectral reflectance characteristics and thus mineralogy and petrology of ordinary chondrites as measured in the laboratory. We are looking for asteroids with spectral characteristics of ordinary chondrites near the 3:1 Kirkwood Gap. In another program, we are investigating possible alteration processes on the surface of asteroids of ordinary chondritic assemblages.

b) Progress - Near-infrared spectra have been acquired of asteroids near the 3:1 Kirkwood gap. No spectra with features similar to those of ordinary chondrite powders measured in the lab were found. Asteroids near this region of the main belt have a bimodal distribution of spectral types. Albedoes for these asteroids from the IRAS asteroid catalogue also show a bimodal distribution. These asteorids which have measured reflectance spectra are all larger than 100 km.

c) Plan for next year - We will measure reflectance of smaller asteroids in this region of the main belt (2.5 AU). We will be testing the assumption that ordinary chondrites are fragments of totally disrupted parent bodies. A CCD spectrometer on large telescopes will permit us to observe smaller asteroids. We will determine measureable spectral parameters which are diagnostic of ordinary chondrite meteorites using image processing techniques, and apply these criteria to asteroid spectra to interpret their mineralogy and petrology.

d) Bibliography

McFadden, L.A. and Vilas, F., Lunar and Planetary Science XVIII, 614-615, 1987.

McFadden and Vilas . . in preparation.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

The radial velocity search for extrasolar planets
Grant: NAG2-52, administered by NASA/Ames Research Center

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Robert S. McMillan and Peter H. Smith

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

We continued to operate a Doppler spectrometer that is accurate enough to detect perturbations due to planets and small-amplitude pulsations of stars. Observations need to span a minimum of five years to detect large planets.

During the report year the instrument was upgraded with a quieter CCD system, a vibration-damped and -isolated optical table, and an insulated "clean" room. Considerable experience has been acquired with the operation and calibration of this instrument; it is being frequently calibrated to $\pm$ 6 meters/sec in Doppler shift. The standard deviation of a one-hour exposure on a solar-type star of blue magnitude 4.0 is $\pm$ 12 m/s. This random error "averages down" through an observing season, giving adequate accuracy for the search for planets. Observations of solar-type stars began in September 1985. A total of 5168 observations of 15 stars have been made on a total of 148 nights between 1985 Sept. 24 and 1987 May 14 UT. The accuracy of the seasonal averages of observations of a star depend more on the number of nights on which the star was observed than on the number of observations. The average number of nights per star is 10 and the total number of "star-nights" is 399.

We have discovered a 1.84-day oscillation of the radial velocity of Arcturus, two modes of short-period oscillations in Pollux, and non-variability of the radial velocity of Eta Cas A, previously suspected to be a spectroscopic binary. These data also rule out previously-suspected 97-minute oscillations in the radial velocity of Arcturus.

During FY '88 we plan to continue our observing, extending the time base of our data series as well as adding more stars to our program. More findings on stellar pulsation and binary orbital motion are expected during the coming year, with emphases on longer time scales of variation and fainter stars.

Refereed Paper:

"Evidence for Pulsations in the Doppler Shift of Arcturus", P. H. Smith, R. S. McMillan, and W. J. Merline, Ap. J. (Letters), 317, L79-L84.

Papers in proceedings of meetings:

"A Fabry-Perot Interferometer for Accurate Measurement of Temporal Changes of Stellar Doppler Shift", 1986, R. S. McMillan, P. H. Smith, J. E. Frecker, W. J. Merline, and M. L. Perry. In Proc. S. P. I. E. 627, "Instrumentation in Astronomy - VI", ed. D. L. Crawford, pp. 2-19.

"A Survey for Doppler-Shift Oscillations in K Giants", 1986, P. H. Smith, R. S. McMillan, and W. J. Merline, in Proc. I. A. U. Symp. 123, "Helio- and Astero-seismology", Dordrecht-Reidel, in press.

Five abstracts of talks presented at meetings in 1986/87 are not listed here.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Occultation Studies of the Solar System
NASA Grant NSG-7603

PERFORMING ORGANIZATION
Lowell Observatory
1400 West Mars Hill Road
Flagstaff, Arizona 86001

INVESTIGATOR'S NAME
Robert L. Millis

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Occultations of stars by planets, asteroids, comets, and satellites provide opportunities to probe the characteristics of the occulting bodies in ways that are otherwise impossible from the surface of the Earth. For example, the Rings of Uranus were discovered and precisely mapped by observation of an occultation even though decades of prior telescopic study of the planet had failed to give any indication of their presence. In this investigation, we seek to identify upcoming occultations, provide accurate predictions for the more favorable events, and observe those that are most important. We are particularly striving to measure the dimensions of selected asteroids, to establish the size of Pluto and the extent of its atmosphere, to identify occultations involving Triton, and to measure the distribution of dust or icy grains in the inner coma of a comet.

b. During the past year, we completed a lengthy analysis of data from the 13 November 1984 occultation by Ceres. This collaborative study, which involved investigators from 14 institutions, yielded the precise dimensions of this minor planet, its bulk density, and clues to its internal structure. The results are in press in *Icarus*. Another accomplishment of the past year has been the reorganization of IAU Commission 20's Working Group on Occultations. Coordinators in various parts of the world have been recruited, and a short list of asteroid events deserving special effort in 1987 has been compiled. Prediction updates, based on astrometry with the Lowell and Lick astrographs, were provided for the 7 targeted events which have occurred so far. Three were observed successfully: one in the northeastern U.S., one in the USSR, and one in New Zealand. Finally, we have completed a search for occultations of stars in the SAO, AGK, Perth 70, and Lick *Voyager* catalogs by asteroids during 1988 and 1989. Approximately 100 events worthy of further study were found.

c. In the upcoming year, we will be working with colleagues at MIT to produce accurate predictions for the 9 June 1988 occultation of a star by Pluto. Previous efforts to observe occultations by Pluto have been unsuccessful because of unreliable predictions. We have been taking plates of Pluto with the Lowell astrograph since December 1986 and will continue to do so through the next year. Additionally, we are collaborating with colleagues at the U.S. Naval Observatory to use CCD astrometric techniques for this prediction. If feasible, we will attempt to observe the occultation with portable or fixed equipment as appropriate. Successful observations will tell us the planet's precise size, its bulk density (an important clue to composition), and the density profile of Pluto's atmosphere. Additionally, we plan to observe asteroid occultations in North America. Favorable opportunities include occultations by Bamberga and Europa. Efforts to predict occultations of stars by comets will continue at a low level with Comet P/Borrelly as the prime target. A search for occultations of stars by Triton will be conducted in support of the *Voyager* mission. Finally, analysis and publication of data already in hand will be pursued.

SUMMARY BIBLIOGRAPHY

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

LUNAR AND PLANETARY STUDIES

PERFORMING ORGANIZATION

California Institute of Technology

INVESTIGATOR'S NAME

D. O. Muhleman, P. Goldreich, A. P. Ingersoll, J. A. Westphal

DESCRIPTION *(a. brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A) This grant supports the core program in planetary astronomy at Caltech under the direction of Professors Goldreich, Ingersoll, Muhleman and Westphal. The research includes observations in the IR, subMM, MM and CM wavelengths at National and Caltech Observatories with a strong emphasis on integrating the observations with spacecraft data and with models of atmospheric structure, dynamics and chemistry. B) Muhleman's group have made extensive observations at the VLA of Saturn, Uranus and Neptune which are being interpreted in terms of deep atmospheric structures which are obvious in the 2 and 6 cm maps of Saturn and Uranus. VLA observations also supply unique data on Saturn's rings such as polarization due to right-angle scattering and forward scattering in the B-Ring. Prof. Ingersoll and his graduate students have continued their work on modeling the heat balance and dynamical circulation of planetary atmospheres. Friedson and Ingersoll (1987) calculated the expected latitudinal temperature variation on Uranus and compared it to the Voyager IRIS observations at 600 mbar. Comparisons with radio brightness temperature variations with latitude (Muhleman's VLA data) are possible, and should reveal facts about the ammonia circulation at pressures of 10 bars and more. During its encounter with Uranus, Voyager discovered several small satellites. Goldreich and Porco (1987) have identified several orbital resonances involving these satellites and the Uranian rings. Resonances are found to fall at both the inner and outer edges of the epsilon ring and at the outer edge of the delta ring. Moreover, the m=2 distortion of the delta ring is shown to correspond to an excited normal mode. These kinematic results imply that the ring radius scale derived from ground based occultation data is too large by about 0.0124 percent. Goldreich and Porco (1987) show that the satellite torques exerted at the inner and outer edges of the epsilon ring are capable of supplying and removing the angular momentum which viscous stresses transport outward across the ring. Thus, the shepherding of the epsilon by 1986U7 and 1986U8 is established beyond reasonable doubt. C) Observational projects at the VLA for next year will include Uranus, Saturn and the Jovian satellites. The study of the Venus atmospheric circulation using the CO molecular line will continue at Kitt Peak, Mauna Kea and the Owens Valley Radio Observatory. Searches for CO in Saturn and Uranus will be made at Mauna Kea, and recent Saturn CO data from Kitt Peak will be used as an upper limit. Ingersoll and students will work with Muhleman to understand the latitudinal variation of radio brightness temperature on the giant planets. Ingersoll's group will be analyzing changes in absolute vorticity (rate of spin) of fluid elements in Jupiter's atmosphere for what they reveal about the underlying potential temperature and zonal velocity structure. Goldreich, Tremaine and Borderies will continue their analysis of the dynamics of Saturn's and Uranus' rings and will extend the development of their shepherding satellite theory. Prof. Westphal will begin a new IR project at the IRTM on Mauna Kea.

D) Berge, G.L., D.O. Muhleman, D. Rudy and R. Lindfield, VLA Observations of Uranus at 2.0 cm. Submitted to Icarus, 1987.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Submillimeter and Millimeter Observations of Solar System Objects

PERFORMING ORGANIZATION

CALIFORNIA INSTITUTE OF TECHNOLOGY

INVESTIGATOR'S NAME

D.O. Muhleman, Professor of Planetary Science

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

A) This small grant supports the actual making of observations at Caltech's two radio observatories: The Owens Valley Radio Observatory (Big Pine, CA) and the Submitllimeter Facility on Mauna Kea, Hawaii. This support includes travel to and subsistence at these Observatories and salary support for the Astronomers' time at the facility and for data reduction and calibration. Both facilities operate in the MM and subMM spectral range in both the continuum and spectroscopic modes. Consequently, all planets (soon to include Pluto), the Jovian satellites, Titan, about a dozen asteroids and the odd comet are observable in a meaningful way. The work is severly limited by the availability of observing time and the costs of travel and subsistence.
B) During the current grant year, we carried out two major observing programs at OVRO: syntheses mapping of Venus in 32 channels of the microwave CO spectrum of the atmosphere and continuum mapping of the 2.6 MM flux density of Saturn and its Rings. The latter work is being done in 5 configurations of the 3 10-meter telescopes of the array at a rate of about one configuration per 2 months (to be completed in June '87). The Venus spectral line mapping was done in a week with 3 rapid configuration changes but is a very complex experiment since the CO abundance on Venus is a function of altitude, longitude and latitude (plus time which is why the synthesis must be done in one week). We have plans to search for CO on Saturn and Uranus in this grant year (July?) at the Mauna Kea facility. The detection of CO (or strong upper limits) in the stratospheres of these planets is extremely important for the understanding of the photochemistry and the origin thd evolution of this atmospheres.
C) The observing program for the next season in the MM spectral range includes continuum observations of Jupiter during the Oct '87 special campaign and continuum and spectral line observations of Temple 2 to search for dust in the first case and CO and HCN in the second. Toward the end of next observing season, we will continue our CO mapping of Venus with OVRO array and possibly single dish CO mapping in the (3-2) line (350 GHz) at the Submillimeter Telescope if the receiver is operational by then.

D) Bibliography:

"Aperture Synthesis Observations of Saturn and its Rings at 2.7mm Wavelength." Dowling, T.E., D.O. Muhleman and G.L. Berge, ICARUS 70, No. 3, 1987.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Photometry of Comet Halley

PERFORMING ORGANIZATION

Department of Physics and Astronomy
The University of Iowa
Iowa City, Iowa 52242-1479

INVESTIGATOR'S NAME

John S. Neff

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) The aim of this study is to develop a model for the emission of dust and gas from the nucleus of a comet and refine the model by critical comparison with filter photometry of comets and other relevant observations.

(b) The reduction of the filter photometry of P/Halley and P/Giacobini-Zinner is nearly complete. The normalized intensity profiles along the sun-antisun have been reduced. The determination of the absolute intensity profiles have been delayed until additional observation of standard stars have been completed.

The model for the emission and subsequent motion of neutral dust has been completed by Tracy Ellis. He has also modified this model to allow the study of the motion of charged dust particles under the influence of both gravity and the interplanetary field. Computed continuous spectra as a function of position on the sky have been used to compute normalized intensity profiles for comparison with the filter observations. Good agreement has been obtained for the observations of P/Halley. A paper on this work is in preparation.

The model for the emission of and subsequent motion of neutral and ionized gas from the nucleus of a comet has been started. The preliminary results appear to be in qualitative agreement with the images of the comet taken in spectral ranges centered on molecular bands.

(c) We intend to complete the data reduction and the models for the emission and subequent motion of the gas. We also intend to compute the thermal emission of the dust for comparison with thermal images. We also intend to compute the molecular band spectrum as a function of position near the nucleus of the comet.

We also intend to reexamine the comparison of the observed dust particle impact rate on the ICE spacecraft during the flyby past P/Giacobini-Zinner with the computed rate from our model from P/Giacobini-Zinner. The model has been improved and the calibration of the mass sensitivity of the ICE plasma wave detector has also been improved.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Physical Processes in Comets

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

R. L. Newburn Jr., Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. The objectives of this work unit are to make quantitative observations of the physical properties of comets, to determine from them the behavior of the gases and dust in each object studied, and to derive improved models of the cometary nucleus from that behavior. Comets vary greatly one from the other in dust-to-gas ratio and in the relative abundance of gases, as well as in absolute activity. A given comet shows great change with heliocentric distance, as well as changes from apparition to apparition. The full range of cometary behavior must be understood, if maximum value is to be obtained from spacecraft studies, and if suitable models are to be prepared for spacecraft design.

b. Results of the S/C flybys of Halley were used to reconsider the way in which comets are modelled and reported at Heidelberg, then submitted for publication. Data on Comet S-S-F acquired at Lick and the IRTF in 1983 were analyzed and submitted for publication. Old and new data on 20 comets were analyzed using post-Halley modelling techniques and presented in Brussels. It was decided that still further improvement is possible, however, so these data were not submitted to the Brussels Proceedings for publication.

c. With the availability of real solar UV flux data from SME, all H_2O abundances derived from [OI] will be analyzed for the actual date of measurement. The vectorial model will be programmed for abundance derivations and used whenever possible in preference to the less accurate Haser model. The importance of combined visible and IR data has become ever more obvious, so I will observe with Hanner at the IRTF as well as with Spinrad at Lick. Separation of dust and nucleus require off nucleus data as well as nucleus centered, so this too will be implemented. Major emphasis will be placed on P/Tempel 2.

d. Divine, N. and Newburn, R. L. Jr., "Modeling Halley Before and After the Encounters," Astron. Astrophys., submitted 2/87.

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Newburn, R. and Spinrad, H., "Dust and Gas Production in Twenty Comets," Symposium on the Diversity and Similarity in Comets, Brussels, 4/87 (to be expanded before publication).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Imaging Studies of Comets

PERFORMING ORGANIZATION

Laboratory for Astronomy and Solar Physics
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME

Malcolm B. Niedner, Jr., Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a.) The Joint Observatory for Cometary Research (JOCR) is jointly run by NASA-GSFC and the New Mexico Institute of Mining and Technology. JOCR is dedicated to observing comets, with emphasis on wide-field imaging of the plasma tail and on understanding the solar-wind interaction with bright comets. JOCR is located under dark skies on South Baldy mountain (elevation 10,600 feet) near Socorro, NM, and is one of the last truly dark sites in the continental U.S. The principal instrument is a 14-inch "Comet Schmidt" which records an $8^{o}x10^{o}$ field onto 4"x5" plates. A 16" Newtonian/Cass. also exists on site and will be available for observations of future bright comets with narrow-band imaging of the near-nuclear region after the completion of several new detectors. JOCR imagery of bright comets since 1973 has resulted in several important published findings concerning cometary plasma structure and solar-wind interactions.

b.) After extensive renovation and upgrading of the facility, including addition of living quarters on the mountain, 275 plates of Halley's Comet were obtained during 94 nights over the interval 1985 July 20-1986 July 12, and are now being digitized and archived into the Large-Scale Phenomena (L-SP) archive of the International Halley Watch (IHW) at NASA-GSFC. This large yield of plates places JOCR at the highest level of productivity of the L-SP's 100+ contributing observatories. JOCR's imagery captured many of the comet's most plasma-active periods such as the January 10-11 and March 20-22 Disconnection Events (DE's). In addition to being digitized, the plates are being reduced for positional and kinematical information on such tail structures.

c.) Plans include obtaining CCD photometry of stars along Halley's path for determining Halley's variable ion production rate seen in the imagery, further development of the 16" Newtonian/Cass. instrument for the post-Halley era, continued analysis of the Halley/G-Z plate material, and a sabbatical year at JOCR for GSFC's Dr. D. A. Klinglesmith. The purposes of his visit are to conduct the CCD program (above) and to assist the upgrading of instruments and the identification of new research projects.

d.) "Dynamics of Cometary Plasma Tails, M. B. Niedner, Advances in Space Research, 6, pp. 315-327 (1986); "Plasma-Tail Activity at the time of the VEGA Encounters", M. B. Niedner and K. Schwingenschuh, Proceedings of the ESLAB Symposium on Halley's Comet, Volume III, 1986 October 27-31, Heidelberg, FRG, p. 419 (1986).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

CCD Camera System for Cometary Research

PERFORMING ORGANIZATION

Laboratory for Astronomy and Solar Physics
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME

Ronald J. Oliversen

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) The objective is to upgrade the NASA/GSFC 36" telescope and instrumentation to permit an effective monitoring program of cometary activity by means of narrow-band imaging and spectroscopic techniques.

b) A general overhaul of the observatory facility has begun; in particular, the telescope mirrors were cleaned, the guide box was refurbished, and the Boller-Chivens Cassegrain spectrograph was cleaned, realigned, and the collimating mirror realuminized. We have developed and adapted data reduction algorithms for the cometary monitoring program based on our analysis, in collaboration with the Univ. of Wisc., of very narrow-band (0.25 A) images and high spectral resolution scans of Comet Halley in the [O I] 6300 A emission line. These Comet Halley data showed the [O I] distribution is due to the photo-dissociation of both H_2O and OH.

c) We will equip the observatory with a commercially available CCD camera system, which is controlled by an IBM AT computer, and interface it with the NASA/GSFC 36-inch telescope which is already equipped with a non-sidereal drive capable of tracking comets. The CCD system will be coupled to a narrow-band interference filter imager and a long-slit spectrograph to provide regular and well-calibrated spatial and spectral observations of comets. The large dynamic range, low noise characteristics and high quantum efficiency of CCDs overcome the cometary observational difficulties of a large range of intensities and faint extended features. Photometric narrow-band images in selected emission lines or bands (e.g., C_2, CN, C_3, [O I], H_2O^+) and the continuum, as well as long-slit spectroscopy will determine gas to dust column density ratios, abundances, production rates, and scale lengths as a function of heliocentric distances. Monitoring of cometary activity on both its pre- and post-perihelion orbital phases will provide information concerning the chemical homogenuity of the nucleus, place tighter constraints on chemical models of the coma, and improve our understanding of the solar wind/radiation interaction with coma and tail structures.

d) **Spatial Distribution of [O I] 6300A Emission Determined from Narrow-Band Images of Halley's Comet**, F.L. Roesler, F. Scherb, K. Magee-Sauer, J. Harlander, R.J. Reynolds, R.J. Oliversen, R.V. Yelle, and A.L. Broadfoot 1986, in Proceeding of the ESLAB Symposium on Hally's Comet, 1986 October 27-31, Heidelberg, FRG.

Roesler, F.L., F. Scherb, K. Magee-Sauer, J. Harlander, R.J. Reynolds, R.J. Oliversen, R.V. Yelle, and A.L. Broadfoot: Spatial Distribution of [O I] 6300A Emission Determined from Narrow-Band Images of Halley's Comet. Proceedings of the ESLAB Symposium on Halley's Comet,]986 October 27-31, Heidelberg, FRG.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Observations of Planetary Atmospheres

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

G. S. Orton, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Obtain infrared data on planetary atmospheres which provide information on several aspects of structure and composition. Observations include direct mission real time support as well as baseline monitoring preceeding mission encounters. Besides providing a broader information context for spacecraft experiment data analysis, observations will provide the quantitative data base required for designing optimum remote sensing sequences evaluating competing science priorities.

b. Filtered radiometric observations of Uranus and Neptune at 21 and 32 μm were published. Spectra of Uranus and Neptune at 7-14 and 17-23 μm were published providing discovery of C_2H_2 and stratospheric haze in Uranus, strong thermal inversion, seasonal C_2H_6 variability and "unenhanced" CH_3D/CH_4 ratio in Neptune. Spectra of Uranus and Neptune at 1.25-2.45 m were obtained, providing evidence for diurnal stratospheric cloud variations. Exploration of Jupiter and Saturn via monitoring of thermal and near-infrared images continued.

c. Jovian and Saturnian monitoring will continue, and coordination with Jupiter Watch program initiated. Higher spectral resolution observations of Neptune will begin. Implementation of "routine" geometric and photometric data reduction programs for infrared images will be completed in preliminary form. Analysis of calibrated central meridian scans of Jupiter from 1981-1983 will be completed.

d. G. Orton et al., 1986. Hydrocarbons in the stratospheres of Uranus and Neptune. Bull. Amer. Astron. Soc. 18, 764; J. Caldwell et al., 1986. Infrared images of Jupiter and Saturn. Bull. Amer. Astron. Soc. 18, 789; G. Orton, 1986. Spatial and temporal variability of infrared-observable properties of the Jovian atmosphere: A partial survey. In Atmospheres of the Jovian Planets, NASA CP-2441, pp 19-25; G. Orton et al., 1987. Temporal changes of temperature and cloud structure in the Jovian atmosphere, 1984-1986: Results of thermal imaging. Bull. Amer. Astron. Soc. 19, 638; Orton et al., 1987. Infrared radiometry of Uranus and Neptune at 21 and 32 μm. Icarus 69, 230-238; Orton et al., 1987. The spectra of Uranus and Neptune at 7-14 and 17-23 μm. Icarus, in press.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radar Investigation of Asteroids and Planetary Satellites

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

S. J. Ostro, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. Objective: Radar reconnaissance of near-Earth asteroids, mainbelt asteroids, Jupiter's Galilean satellites, the Martian satellites, and Titan, using the Arecibo λ13-cm and the Goldstone λ3.5-cm systems. Measurements of echo strength, polarization, and delay/Doppler distribution of echo power yield information about dimensions, spin vector, large-scale topography, cm-to-m-scale morphology, near-surface bulk density, and metal concentration.

B. Progress: Dual-polarization radar signatures have been measured for nearly 1% of the numbered mainbelt asteroids and 15% of the known near-Earth asteroids. The diversity of 13-cm radar signatures is extreme, revealing huge differences in surface morphologies, bulk densities, and metal concentrations. For S-class objects, there is an inverse relation between small-scale roughness and target size. 216 Kleopatra's echo spectra indicate a dumbbell shape whose convex hull has dimensions within ~30 km of 270x120 km. For near-Earth asteroids, polar silhouettes range from slightly non-spherical to highly elongated and clearly nonelliptical. Delay-Doppler resolution of echoes from the rendezvous-mission candidate 1627 Ivar has yielded the first 2-D images of an asteroid; they show Ivar to be elongated, irregular, and bifurcated. Asteroid 1986 DA has an equally intriguing shape and a radar albedo that apparently requires a nearly solid metallic surface; this object might be genetically related to some iron meteorites. Echoes from the Jupiter-approaching object 1986 JK, detected at 11 lunar distances from Earth three weeks after its discovery, yielded Doppler-frequency measurements that will help to ensure its optical recovery.

C. Proposed Work: 1) Observations of at least eight asteroids during FY88, including 4 Vesta, 20 Massalia, 105 Artemis, 2212 Hephaistos, 1980 PA, and the rendezvous-mission candidate 1982 XB. Echoes from the two unnumbered near-Earth asteroids probably will be strong enough for high-resolution imaging. 2) The first 13-cm radar observations of the Galilean satellites since 1979, using a more sensitive system than was available then. Prime objectives include measurement of Io's dual-polarization radar signature. 3) A 4-cm investigation of Callisto. 4) The first radar observations of Phobos and Deimos. 5) Publication of a large backlog of results for 40 asteroids.

D. Summary Bibliography: 3 journal/book articles published or in press; 6 abstracts published.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

SPECTROSCOPIC OBSERVATIONS OF THE PLANETS

PERFORMING ORGANIZATION

RESEARCH FOUNDATION
STATE UNIVERSITY OF NEW YORK
STONY BROOK, NEW YORK 11794-2100

INVESTIGATOR'S NAME

TOBIAS OWEN

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Strategy: This research consists of the acquisition and interpretation of ground-based spectroscopic observations of planets, satellites and comets.

b) Progress and Accomplishments: In collaboration with C. de Bergh and B. Lutz, a systematic program of determining D/H in the outer solar system was undertaken. A review of results to date published in NATURE demonstrated the existence of two distinct reservoirs of deuterium in the outer solar system. An observing run in January extended this study to Mars, where we discovered deuterium for the first time, in the form of HDO. Preliminary analysis suggests an enrichment of D/H on Mars compared with Earth by a few times.

c) This Year's Program: We have just secured new observations of Titan and Saturn's icy satellites with the IRTF and CGAS. Time has been granted on the CFH telescope for July so we can complete our D/H program by observing Neptune. In October, we will carry out a specific study of Jupiter's Great Red Spot with the IRTF and CGAS. An article on D/H on Titan has been submitted and papers on $^{12}C/^{13}C$ on Saturn and D/H on Mars are in preparation.

d) Summary Bibliography - 1986

"Constraints on the NH_3 and PH_3 Distributions in the Great Red Spot" (with R. Wagener and J. Caldwell), Icarus 66, 188 (1986).

"Deuterium in the Outer Solar System" (with C. de Bergh and B. L. Lutz), Nature 320, 244-246 (1986).

"A Study of the Upper Atmosphere of Uranus using IUE" (with Th. Encrenaz, M. Combes, S. K. Atreya, P. N. Romani, K. Fricke, V. Moore, G. Hunt, R. Wagener, J. Caldwell, P. Butterworth), Astron. and Astrophys. 162, 317 (1986).

"Update of the Anders-Owen Model for Martian Volatiles" - Abstract - (LPI Technical Report No. 86-07 p. 31-32 (1986).

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C.2

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Compositional Studies of Mercury's Atmosphere

PERFORMING ORGANIZATION
Space Science Branch
Solar Systems Exploration Division
Space and Life Sciences Directorate
NASA Johnson Space Center, Houston, TX 77058

INVESTIGATOR'S NAME

Potter, A. E.

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

13. Strategy of Investigation: Mercury's atmosphere will be studied by means of high resolution spectroscopy of sodium and potassium resonance line emissions. The variation of metal vapor abundances with time, and with location on the planet will be measured, with a view to understanding the origin and evolution of these elements in the Mercury atmosphere. Additional elemental species which may be detectable in the atmosphere will be sought, as for example magnesium and calcium. Observations will made at Kitt Peak National Observatory and at the University of Texas McDonald Observatory.

b. Prior Accomplishments: In 1985, Potter and Morgan identified sodium as a major constituent of Mercury's tenuous atmosphere. Observations of the sodium around different maximum elongations appear to show that the abundance of sodium depends upon the radial velocity of the planet relative to the sun. The presence of potassium in the atmosphere has now also been established by Potter and Morgan.

c. Planned Accomplishments: Secular variations of sodium and potassium abundances will be studied by long-term monitoring of the resonance emissions. The distribution of the metal vapors across the planet surface will be studied, using an image stabilizer to minimize image movements during the observations. The profile of the sodium resonance emission lines will be measured at resolutions of at least 600,000 in order to determine the velocity distribution of the sodium in the atmosphere. Also, the search for other elemental species in the Mercurian atmosphere will be continued.

d. Summary Bibliography: (1) Potter, A. and T. Morgan (1985) Discovery of Sodium in the Atmosphere of Mercury. Science, v. 229, pp.651-3.
(2) Potter, A. and T. Morgan (1986) Potassium in the Atmosphere of Mercury. Icarus, in press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Ground-Based Observations of Comet Halley and the Jupiter/Io Plasma Torus

PERFORMING ORGANIZATION

Physics Department
University of Wisconsin
Madison, WI 53706

INVESTIGATOR'S NAME

F. Scherb
F. L. Roesler

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) We have been conducting a program of observations of cometary and Jupiter plasma torus emissions using Fabry-Perot spectrometers in both scanning and imaging modes. Our techniques combine high spectral resolution (in order to isolate individual spectral emission lines) with high sensitivity (in order to detect the emissions at very low intensities).

(b) During the past year we have concentrated on organizing and analyzing the large body of data obtained from our observations of Comet Halley from November 1985 to May 1986. Preliminary results of this work were presented at the 26th COSPAR Symposium in Toulouse, France in July 1986, at the 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, Germany, October 1986, and at the Symposium on the Diversity and Similarity of Comets, Brussels, Belgium, April 1987. Reports on this work are included in the proceedings of all these symposiums. A paper on some of this work has been completed and will be submitted to Icarus within a few days.

(c) We will continue intensive analysis of our Halley data in collaboration with Dr. R. Oliversen of Goddard Space Flight Center. We have also begun a collaboration with Drs. H. Hippelein and G. Münch of the Max-Planck-Institut für Astronomie, Heidelberg to analyze Fabry-Perot observations of Halley which they obtained in collaboration with Dr. J. Trauger of JPL. We expect this work to lead to improved values of scale lengths of important cometary molecules and to more accurate values of gas production rates.

We also plan to resume observations of the Jupiter plasma torus beginning in July 1987 and continuing through 1987-1988. This work will be done in collaboration with Dr. R. Oliversen at Goddard Space Flight Center and the observing program will be coordinated as much as possible with observations by other investigators. For example, we will try to coordinate our July-August 1987 observations with IUE observations of the torus by Dr. D. Shemansky of the University of Arizona, and in October 1987 we will try to observe during Jupiter Watch Week, October 15-21.

(d) Publications

1. Roesler, F. L., F. Scherb, K. Magee-Sauer, J. Harlander, R. J. Reynolds, R. J. Oliversen, R. V. Yelle, and A. L. Broadfoot: Spatial Distribution of [OI] 6300 Å Emission Determined from Narrow-Band Images of Halley's Comet. Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, ESA SP-250, p. 413, December 1986.

2. Roesler, F. L., F. Scherb, K. Magee, J. Harlander, R. J. Reynolds, R. V. Yelle, A. L. Broadfoot, and R. J. Oliversen: High Spectral Resolution Line Profiles and Images of Comet Halley. Adv. Space Res. 5, 279, 1986.

3. Roesler, F. L., F. Scherb, R. J. Oliversen, K. Magee-Sauer, J. Harlander, and R. J. Reynolds: Spatial Distribution of $O(^1D)$ from Comet Halley. Proc. Symposium on the Diversity and Similarity of Comets, Brussels, 1987.

4. Roesler, F. L., F. Scherb, K. Magee-Sauer, J. Harlander, and R. J. Oliversen: Spatial Distribution of $O(^1D)$ from Comet Halley. to be submitted to Icarus, 1987.

5. Scherb, F., F. L. Roesler, K. Magee-Sauer, J. Harlander, and R. J. Reynolds: Fabry-Perot Ground-Based Observations of Comet Halley. Adv. Space Res. 5, 275, 1986.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radar Studies in the Solar System

PERFORMING ORGANIZATION
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, MA. 02138

INVESTIGATOR'S NAME

Irwin I. Shapiro

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. We are collaborating with colleagues at JPL and Arecibo Observatory in collecting, analyzing, and interpreting radar observations of asteroids, comets, and planets.

b. Last year's progress includes preparation of observing ephemerides for 10 asteroids and preliminary analysis of the resulting radar data. In addition, covariance studies were performed to ascertain the benefits to be expected from radar observations of Icarus scheduled for June of 1987. Radar observations of Mercury were made, but, unfortunately, none were made simultaneously at Arecibo and Goldstone.

c. We will continue to participate in the ongoing program of asteroid observations with 8 asteroids tentatively scheduled over the next year. Preparations will be made for the proposed observations of Mercury "closure points," and of Martian and Jovian satellites, including an improvement of the planetary ephemeris based on all presently available high-precision data. The observations of Mercury and Icarus will lead to a determination of (or tightened bound on) the Sun's gravitational quadrupole moment and an improved test of general relativity.

d. Ostro, S. J., D. B. Campbell, and I. I. Shapiro, Mainbelt asteroids: dual-polarization radar observations, Science, 442-446, 1985.

Harmon, J. K., D. B. Campbell, J. W. Head, D. L. Bindschadler, and I. I. Shapiro, Radar altimetry of Mercury: a preliminary analysis, J. Geophys. Res. 91, 385-401, 1986.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE: A Continued Program of Planetary Study at The University of Texas McDonald Observatory

PERFORMING ORGANIZATION:
McDonald Observatory
The University of Texas at Austin

INVESTIGATOR'S NAME:
Harlan J. Smith
William D. Cochran
Laurence M. Trafton
Edwin S. Barker

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. This program conducts solar system research in support of NASA missions and of general astronomical interest. Investigations of the composition, physical characteristics, and changes in solar system bodies are conducted primarily utilizing facilities of McDonald Observatory, but also utilizing various space vehicles where appropriate.

b. We have studied a large group of active "normal" comets and determined that the Haser model production rates of C_2 and C_3 were well correlated with CN production rates. We then looked at a sample of 27 low activity comets, which were selected to have no C_2 or C_3 emissions, and compared them with the normal comets. We find that the low activity comets are anomolously depleted in C_2 and C_3 relative to CN, for reasons as yet unknown. We observed unexpected C_3 emission in comet Halley at a heliocentric distance of 4.8 au. Comet Halley still looks like a normal comet at this distance, based on the ratio of C_3 to CN. High resolution spectra of NH rotational lines in comet Halley indicate that the NH excitation mechanism in the coma is dominated by the process of radiative decay, rather than resonance fluorescence or collisions. We have continued a program of 15-25Å resolution spectrophotometry of asteroids in the 5000-10000Å spectral region, which will provide important information on the surface composition of asteroids, particularly the C and related types. We have continued our program of spectrophotometry of Pluto and Charon, including observations of two eclipses. From these, we obtained the first spectra of the individual bodies Pluto and Charon in the 5000-10000Å spectral region, which indicate that Charon's surface appears to be devoid of volatiles and any atmosphere. We have obtained an upper limit on the H_2 quadrupole $S_1(1)$ emission for Jupiter's north auroral region equal to 1/3 the value predicted by Kim and Maguire, indicating strong collisional quenching of H_2. We have also obtained spectra of Jupiter's fundamental pressure-induced H_2 band at various positions on the disk. The northern hood is darker than the southern, possibly the result of enhanced photochemistry and auroral visibility during the northern summer. Analysis of 1978-80 spectra of Uranus' $(3-0)$ H_2 quadrupole line shapes requires both a high altitude and a low altitude haze and a fraction of normal H_2 equal to 0.25 ± 0.10. Eclipses of Europa by Io were analyzed to use Europa as a mirror to look back through Io's lower atmosphere. Io's atmosphere appears to be collisionally thin above 700km and resembles a 1500K exosphere with a surface density near $2 \times 10^4 cm^3$. The calculated loss rates suggest that the atmosphere is being replaced on a timescale of hours. We have demonstrated that it is possible to use the McDonald 2.7m coudé spectrograph to measure stellar radial velocity variations to a precision of 10-20 m s^{-1}, enabling us to start *now* on a search for extra-solar planetary systems.

c. The Faint Comet Survey will continue to monitor all comets brighter than 19.5 mag available from McDonald Observatory. Some comets will be available for a second apparition, allowing us to examine their long-term evolution. We will examine our Faint Comet Survey database to select comets with activity levels intermediate to the normal comets and the low activity comets in order to determine if there is a gradient in the ratios of the C_2 and C_3 to CN production rates. We will devote extensive effort to continuing to use the Pluto/Charon eclipses to explore this interesting system by attempting to obtain visual and infrared spectrophotometry of each available eclipse. We will continue our new program of near infrared spectroscopy of planetary atmospheres. Now that we have demonstrated our ability to make high precision measurements of stellar radial velocity variations, we will immediately begin a systematic observing program of searching for extra-solar planetary systems.

Relevant Publications and Presentations

- Barker, E. S. and Green, J. R.: "CCD Filter Photometry of P/Halley and P/Giacobini-Zinner" *Proceedings of the 20th ESLAB Symposium on the Exploration of Halley's Comet*, ESA SP-250 **1**, 481, 1986.
- Binzel, R. P., Green, J. R., and Opal, C. B.: "Chaotic Rotation of Hyperion?" *Nature* **320**, 511, 1986.
- Binzel, R. P., Cochran, A. L., Barker, E. S., Tholen, D. J., Barucci, A., Martino, M. Di., Greenberg, R., Weidenschilling, S. J., Chapman, C. R., and Davis, D. R.: "Coordinated Observations of Asteroids 1219 Britta and 1972 Y Xing" *Icarus* in press, 1987.
- Binzel, R. P.: "A photoelectric Survey of 130 Asteroids" *Icarus* in press, 1987.
- Binzel, R. P.: "Collisional evolution in the Eos and Koronis families: Observational and Numerical Results" *Icarus* in press, 1987.
- Cochran, A. L.: "Another Look at Abundance Correlations Among Comets" *Astron. J.* **93**, 231–238, 1987.
- Cochran, A. L. and Barker, E. S.: "Comet Giacobini-Zinner: A Normal Comet?" *Astron. J.* **93**, 239–243, 1987.
- Cochran, A. L. and Barker, E. S.: "Spectrophotometric Observations of Comet Halley" *Proceedings of the 20th ESLAB Symposium on the Exploration of Halley's Comet*, ESA SP-250 **1**, 439–444, 1986.
- Cochran, A. L., Green, J. R., and Barker E. S.: 'The Relationship Between Low Activity Comets and More Active Comets' *Proceedings of the Symposium on the Diversity and Similarity of Comets*, 6–9 April, 1987, Brussels, Belgium, ESA SP-278, in press.
- Cochran, W. D.: "High Resolution Spectroscopy of P/Halley" *Proceedings of the 20th ESLAB Symposium on the Exploration of Halley's Comet*, ESA SP-250 **1**, 317–321, 1986.
- Schneider, N., Hunten, D., Wells, W., and Trafton, L.: "Eclipse Measurements of Io's Sodium Atmosphere" *Science* submitted, 1987.
- Trafton, L.: "Uranus' (3-0) H_2 Quadrupole Line Profiles" *Icarus*, **70**, 13–30, 1987.
- Trafton, L., Stern, S. A., and Gladstone, R.: "The Pluto–Charon System: The Escape of Charon's Primordial Atmosphere" *Icarus* submitted, 1987.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Ground-based Studies of the Outer Planets and Titan in Support of Galileo and Voyager Missions, NSG-7394

PERFORMING ORGANIZATION

Washington University
Dept. of Earth and Planetary Sciences
St. Louis, MO. 63130

INVESTIGATOR'S NAME

Wm. Hayden Smith, 314-889-5638

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a).We obtain spectral images of the outer planets to determine the nature and distribution of molecular and cloud species. This work is coupled closely with the Voyager and Galileo studies of these same atmospheres.

b).We have observed fully resolved H_2 quadrupole lines for all the major planets to determine line profiles or equivalent widths as constraints for detailed atmospheric models. The observed Neptune H_2 $S_3(1)/S_4(1)$ ratio (in 1983) is consistent with the presence of extensive tropospheric methane clouds. We have now obtained H_2 4-0 profiles on an hourly time scale over several Neptunian days in a search for temporal variations due to non-uniform clouds. Our Uranus data for spectrally resolved 4-0 and 3-0 H_2 lines show strong asymmetries which are very sensitive to the vertical P-T and H_2 ortho-para ratio profiles. Global models, being developed in collaboration with K.H.Baines (JPL). Jupiter H_2 observations at ~1" spatial and $\sim 10^6$ spectral resolution will be analysed for the ortho-para ratio. Work is well underway to derive cylinder maps for Jupiter in P, T, and NH_3 abundance from our spatially and spectrally resolved NH_3 for the entire cloud surface of Jupiter. SPIFI spectral imagery for Saturn in the H_2 $S_3(1)$ transition at $\sim 10^5$ spectral resolution are the basis for modelling the spatial variation of specific molecular lines over Saturn's disc. These innovative techniques provide an essential underpinning for the Voyager, the Galileo, and eventually, the Cassini missions study of the atmospheres of the outer planets.

Bibliography for 1985-1986

1. Methane Clouds in the Atmosphere of Neptune, paper in DPS Meeting, Paris, (with K.Baines and W.Schempp), in preparation (1986).
2. Aerosol and Gas Distributions in the Troposphere of Neptune: Constraints from "Visible" Broadband Imagery and Low and High Resolution Spectrophotometry (with K.Baines,J.Bergstralh, R.Terrile,D.Wenkert,J.Neff,and B.Smith), AAS Meeting, Pasadena, January,1987.
3. The Distribution of Major Molecular Species in the Outer Solar System: Constraints on the Molar Fraction of Methane and the Ortho/Para H_2 Distribution in Neptune and Uranus from Ground-based High-Resolution and Broadband Spectroscopy.(with Baines,K.H., Neff,J.S.,Berghstralh,J.T.), Meeting on Origin and Evolution of Planetary and Satellite Atmospheres, Tucson(March,10,1987).
4. Titan's Apparent Continuum from the 6197 A and 6819 A CH_4 Lines (with W.Schempp, J.Simon,and L.Giver),in preparation
5. A Search for the H_2 $S_4(2)$ Line in Jupiter,(with K. Baines), in preparation
6. The D/H Ratio Upper Limit for Jupiter from Profiles for the HD $R_5(0)$ line, with J.Simon, and Baines,K.,in preparation.
7. The D/H Ratio Upper Limit for Uranus, with K.Baines, and Simon,J., in preparation.
8. Spatially Resolved Profiles for H_2, NH_3, and CH_4 in Jupiter: An Inhomogeneous Atmospheric Baseline Model,(with W. Cochran and K.Baines), in preparation.
8. Spectral Imagery of Saturn in the H_2 $S_3(1)$ Transition, in preparation.
9. The H_2 $S_4(0)$ Feature for Jupiter and Saturn. The Ortho-Para Ratio, with J.Simon, in preparation.
10. NH_3 Cylinder Maps for Jupiter, with Baines, K., in preparation.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

High Resolution Spectral Imagery of Periodic and New Comets

PERFORMING ORGANIZATION

Washington University
Department of Earth and Planetary Sciences
St. Louis, MO. 63130

INVESTIGATOR'S NAME

Wm. Hayden Smith, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a). We obtain spectral images of comets to study their dynamics and the nature of their coma constituents over the orbital path.

b). We have discovered that Comet Halley dust does not exhibit the well known and ubiquitous diffuse interstellar features and thus emits dust fundamentally different from interstellar dust. We have sought the $Q_1(1)$ transition of H_2 towards Halley and find that the amount of H_2 consistent with our observations can be produced by the photodissociation of H_2O and CH_4 without a contribution from H_2 interstitally trapped during the comet's formation. We have obtained data to establish abundances for $^{13}C^{12}C$, $^{12}C_2$, $C^{14}N$, $C^{15}N$, [O I] 6300 A, 6363 A, and 5577 A, H_2O^+, OH, NH_2, NH^+, and OH^+, and to seek temporal and spatial variability among these species. Part of the spectral observations were obtained with 1" spatial resolution across 75" of the coma. We also obtained high spectral resolution absorption spectra for K I and selected features of the CN A-X red band in the coma of Giacobinni-Zinner (G-Z) during an apulse, as well as C_2, NH_2, and [O I] data. Some spectral imaging data were acquired (Smith et al.,1987). We imaged Halley in OH Lines near 3080 A and CN near 3880 A in linearly polarized light using an acousto-optic tunable filter (AOTF) with a TI 4849 CCD.

c). Our goal in the continuation of this research is the detailed analysis of our Comet Halley data for publication. Our data contain extensive information on both morphological and excitation processes occuring during our observational sequences. The exploitation of that information is a prime goal of the continuation of our cometary studies.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Astronomy

PERFORMING ORGANIZATION

California Institute of Technology
Pasadena, CA 91125

INVESTIGATOR'S NAME

B. T. Soifer, Senior Research Associate in Physics

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year, c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

In the past year near infrared and optical observations in Planetary Astronomy have been conducted using the telescopes of the Palomar Observatory.

The near infrared observations have focused on the planets and ring systems of the outer solar system. We have continued our program to observe the arc rings of the Neptune system, using the stellar occultations by the Neptune system as it passes through the galactic plane. In the last year we successfully observed the occultation of 27 July 86 on the 200 inch Hale telescope and were fogged out in an attempted observation of the 7 Nov 86 occultation. The 27 July occultation showed one potential arc ring event, but the lack of observation at other observatories precludes classifying this as a confirmed event.

We have begun observations, in collaboration with Tedesco, of the Pluto–Charon mutual eclipse events. Monitoring the light both in and out of the strong methane bands at 1.6 μm and 2.2 μm during these events provides a higher spatial resolution probe of the variation in the surface of these bodies than is possible even with the Space Telescope. In the last year we observed the partial eclipse of Charon by Pluto of 4 March 86. These results showed a deeper methane band during the eclipse, consistent with the idea that Pluto is more covered with methane than is Charon.

The Palomar 48 inch Schmidt telescope is now fully occupied with the "Palomar Sky Survey II–(PSSII)." This grant has supported observers who have devoted substantial effort to searching for comets and asteroids on the plates of the PSSII. As a result, Comet Maury (1985k) and Comet Wilson (1986l) as well as several fast moving asteroids were discovered on the plates of the PSSII.

In the next year we shall continue our observations of the Neptune arc rings and the Pluto–Charon mutual eclipses. The goal of the Neptune observations is to obtain as much information as possible about the structure of the arc ring system. Because the probability of detecting ring events is between 0.1 and 0.2 in each chord, it is crucial to observe as many stellar occultation as possible. We shall observe the events of 25 May 87 and 9 July 87. We shall observe two of the Pluto–Charon mutual eclipse events, one inferior and one superior, to probe the surface distribution of methane on the surfaces of these bodies.

We shall also support inspection of the plates of the PSSII, to find new comets and asteroids.

WORK SUPPORTED BY NGL 05-002-140

Cooke, M.L., Nicholson, P.D., Matthews, K., and Elias, J. 1985, "Occultation Observations of a Possible Neptunian Ring System", *B.A.A.S.* **17**, 719.

Elliot, J.L., French, R.G., Meech, K.J., and Elias, J.H. 1984, "Stucture of the Uranian Rings, I. Square Well Model and Particle Size Constraints", *A. J.* **89**, 1587.

French, R.G. *et al.* 1985, "The 4 May and 24 May 1985 Occultations by the Uranian Rings", *B.A.A.S.* **17**, 85.

Kowal, C., "Small Bodies in the Solar System" in "Astronomy with Schmidt type Telescopes", Capaccioli, M. ed. 1984.

Nicholson, P.D., Showalter, M.R., and Matthews, K 1985, "High Resolution 'Images' of the Uranus Rings Derived from Stellar Occultation Data, *B.A.A.S.* **17**, 699.

Nicholson, P.D. Jones, T.J., and Matthews, K. 1984, "Infrared Observations of the Uranian Rings" in Proceedings I.A.U. Colloq. 75, 169.

IAU Circulars

3982 1984 QA
3988 Comet Kowal-Mrkos (1984n)
4102 Comet Maury (1985k)
4105 Comet Maury (1985k)
4237 1986 NA
4241 Comet Wilson (1986l)
4252 1986 RA

Minor Planet Circular

Fast Moving Asteroid - October 1985

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Spatially Resolved Quantitative Spectroscopy of Comets

PERFORMING ORGANIZATION

University of California, Berkeley

INVESTIGATOR'S NAME

Hyron Spinrad

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

The overall program continues to emphasize optical spectroscopy of periodic comets, taking advantage of the new CCD-technology which permits good spatial and fair spectral-resolution simultaneously.

During the last year the major task has been continuation of the reduction and analysis of two-dimension spectra and some narrow-band imaging of comet P/Halley. The oxygen production rate of the comet was monitored over much of the 1985-86 apparition; the oxygen (and hence its H_2O-parent) production could be well-described by a power-law dependence on heliocentric distance, when the exponent $\alpha = -2.8$ for the pre-perihelion observations and $\alpha = -1.9$ post-perihelion.

The H_2O ion was also well-measured on many of the P/Halley spectrograms; its strength and spatial variation can yield important information on the inner cometary ionosphere. We have started comparing our 14 March 1986 radius-vector aligned H_2O^+ profile with the *in situ* measures from the Giotto Ion Composition Experiment; it appears that some physical insight may come from the comparison, even though the geometries of the two data sets are different.

Finally, Spinrad has collaborated with M. Hanner and R. L. Newburn to study the gas and dust production of the small, earth-grazing comet SSF. In a paper just submitted to the *A.J.*, they found this little comet to have a vanishingly small dust production rate.

In the upcoming year I will continue the leads discussed above, and begin a photometric monitoring program with M. Belton and P. Wehinger, to study the light variation of P/Halley at $r \geq 7$ A.U. We would hope to determine the nuclear spin-rate as the comet recedes from the inner solar system.

Spinrad's Publications on Comets:
May 1986 - May 1987

1. Belton, M.J.S., Wehinger, P., Wyckoff, S., and Spinrad, H. 1986, Proc. 20th ESLAB Symp. on the Exploration of Halley's Comet, Heidelberg; ESA SP-250.

2. McCarthy, P.J., Strauss, M.A., and Spinrad, H., 1986, Proc. 20th ESLAB Symp. on the Exploration of Halley's Comet, Heidelberg; ESA SP-250, p. 87. (The Ionospheric Extent of P/Halley from Ground-Based Observations During the 1985-1986 Apparition.)

3. Meyer-Vernet, N., Strauss, M.A., Steinberg, J.L., Spinrad, H. and McCarthy, P.J. 1987, Astner, J. 93, 474. (Comet P/Giacobini-Zinner Electron and H_2O^+ Column Densities from ICE and Ground-Based Observations.)

4. Slavin, J.A., Goldberg, B.A., Smith, E.J., McComas, D.J., Bame, S.J., Strauss, M.A., and Spinrad, H. 1986, Geophys. Res. Lett. 13, 1085. (The Structure of a Cometary Type I Tail: Ground-Based and ICE Observations of P/Giacobini-Zinner.)

5. Spinrad, H., McCarthy, P.J., and Strauss, M.A. 1986, Proc. 20th ESLAB Symp. on the Exploration of Halley's Comet, Heidelberg, ESA SP-250, p. 437. (Oxygen Production Rates for P/Halley Over Much of the 1985-86 Apparition.)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Disks, Jets and Mass Outflows Associated with Young Stellar Objects

PERFORMING ORGANIZATION

University of Massachusetts

INVESTIGATOR'S NAME

Stephen E. Strom

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy.

Our goal is to detect circumstellar disks associated with ~ 1 $M_\odot$ young stellar objects from ground-based optical and infrared observations to specify the evolutionary behavior and physical environment characterizing these disks, and to understand the role such disks may play in planet-building episodes.

b. Progress and accomplishments.

The properties (size, mass, opacity) of disks associated with 12 low-to-intermediate mass young stellar objects (YSOs) were determined from a combination of spectroscopic studies of stellar winds through observations of [OI] and [SII] line profiles and far infrared observations of these objects. Emission from [OI] and [SII] appear to arise in the outer ($r > 30$ au), low density regions of mass outflows emanating from YSOs. In all cases, the systemic velocity of the forbidden-lines is blue-shifted; no evidence of receding, red-shifted gas is seen. We presume that emission from receding gas is obscured by an optically-opaque circumstellar disk. The minimum size of the obscured disk can be estimated from the extent of the forbidden line emission region derived from the observed [SII] $\lambda 6731/\lambda 6717$ line ratio; for our sample, the estimated disk radii lie in the range $20 < r_d < 1200$ au with a "typical" value $r_d \sim 100$ au. An independent estimate of the disk sizes can be obtained from the observed 60μ flux and the assumption (verified from 3-mm continuum measurements) that the disks are optically thick at this wavelength; the disk sizes computed in this way are comparable to the minimum values derived from the forbidden-line observations. The minimum masses of the disks are estimated to lie on the range 0.02 to 0.02 $M_\odot$. In two cases, R Mon and HL Tau, circumstellar disks, of dimension comparable to those estimated from the forbidden line analysis and the far-IR continuum, have been observed directly using speckle and image reconstruction techniques. We conclude that disks of solar-system sizes and masses are observed around at least 20 per cent of young stars of ~ 1 $M_\odot$. These disks remain optically thick to ages > 3×10^6 yrs.

c. Plans for 1987-1988

During the next year, we hope to identify the epoch of disk clearing (and possible planet building) by observing the [SII] and [OI] forbidden-line profiles in a sample of T Tauri stars selected to cover the age range 10^6 to ~ $3x10^7$ yrs. When the disks surrounding the TTS become optically thin, the forbidden lines should exhibit both blue and red-shifted components. We also expect to use observations of infrared forbidden lines to confirm our hypothesis that the disks are optically thick at λ~60μ. By observing forbidden lines characterized by high ($n > 10^5$ cm^{-3}) critical density (and thus formed in the inner wind regions) we hope to probe the opacity of the disk in regions comparable in dimension to the solar system. This experiment will allow us to determine whether clearing takes place first in the inner disk and to estimate the timescale for disk clearing in the region where terrestrial planets may form.

Radio and Optical Observations of the Jets from L1551 IRS-5, 1985, Ap. J. 290, 587-595 - with R. L. Snell, J. Bally, and K. M. Strom.

A Study of the Morphology and Kinematics of the Dense Gas Associated with Star Forming Regions, 1986, Ap. J., 308, 134 - with M. H. Heyer, R. L. Snell, P. F. Goldsmith and K. M. Strom.

Optical Manifestation of Mass Outflows from Young Stars: An Atlas of CCD Images of Objects, 1986, Ap. J. Suppl. 62, 39 - with K. M. Strom, S. C. Wolff, J. Morgan and M. Wenz.

An Optical Imaging and Polarimetric Study of the Lynds L723 and B335 Molecular Outflow Regions, 1986, A.J., 92, 633-635 - with F. J. Vrba, K. M. Strom, M. H. Heyer.

Extended Far-Infrared Emission Associated with Mass Outflows from Young Stars I. L1551, IRS 5, 1986, Ap.J., 307, L65-68- with S. Edwards, R. L. Snell, T. H. Jarrett, C. A. Beichmann, K. M. Strom

Mass Outflows Associated with Young Stellar Objects, invited review presented at IAU Symposium 115 "Star Forming Regions", Tokyo, Japan, S. E. Strom, K.M. Strom

Anisotropic Winds from T Tauri Stars, 1986, 4th Cambridge Workshop on Cool Stars, Stellar Systems and the Sun, - S. Edwards, S. E. Strom, I. Heyer, K. M. Strom.

High Resolution Images of the L1551 Bipolar Outflow: Evidence for an Expanding, Accelerated Shell," Ap.J., (in press) - G. H. Moriarty-Schieven, R. L. Snell, S. E. Strom, F. P. Schloerb, K. M. Strom.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Pole Orientation, Sidereal Period, and Sense of Rotation of Asteroids

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Ronald C. Taylor

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

Photometric astrometry (PA) is a method to derive from precise timing of lightcurve epochs the pole orientation, sidereal period, and sense of rotation of asteroids. The objectives are to apply PA in physical studies of planetary objects, and with the pole position established, to study the asteroid's shape and/or albedo characteristics.

Recently analyses of asteroids 532 Herculina and 45 Eugenia were completed. Herculina is an interesting object displaying sometimes one and at other times two lightcurve maxima per rotation cycle. Eugenia may have one or more albedo features on its surface.

Present plans include collaboration on an asteroid pole chapter in the new "Asteroids II" text. PA will also be applied to asteroids 3103 198288, 1 Ceres and 3 Juno. Attempts will also be made to determine a model for Eugenia, consistent with observational data, and to improve the Herculina model in light of recent thermal infrared findings.

Taylor, R. C., Birch, P. V., Drummond, J., Pospieszalska-Surdej, A., and Surdej, J.: "Asteroid 532 Herculina: Lightcurves, Pole Orientation and a Model." Icarus 69, 354, 1987.

Taylor, R. C., Birch, P. V., Pospieszalska-Surdej, A., and Surdej, J.: "Asteroid 45 Eugenia. Lightcurves, and the Pole Orientation. Icarus (submitted), 1987.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Asteroid Shapes and Pole Orientation From Visual and Infrared Photometry

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

E. F. Tedesco, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. OBJECTIVE: To develop models of the Pluto-Charon system, including separations, relative sizes, some orbital parameters, density, and an albedo map of the hemisphere of Pluto facing Charon via analysis of Pluto-Charon mutual eclipse event lightcurves.

B. PROGRESS: During FY'86 and '87 observations of Pluto-Charon mutual events were obtained with the Palomar 1.5-meter, Kitt Peak 1.3-meter, and NASA IRTF 3-meter telescopes. First order analytical and numerical models, incorporating shadowing and hemispheric albedo differences between Pluto and Charon were perfected. A paper describing the models was published. IRAS survey observations of Pluto were combined with the results of our eclipse models. This work showed that the thermal flux observed by IRAS can only be explained if Pluto behaves as an isothermal body, *e.g.*, as would be the case if it had a significant atmosphere. A paper describing these results is currently in press in *Nature*. Half-day "Pluto Workshops" were organized and held in connection with the 1985 and 1986 DPS meetings. An international campaign to obtain eclipse lightcurves was organized and a newsletter begun.

C. PROPOSED WORK: During FY'88 we will make additional observations, develop second order eclipse and infrared models, publish the observational results from the previous two years, hold a third Pluto Workshop at the 1987 DPS meeting, continue directing the international campaign and publication of the Pluto newsletter. Increased funding support is required to allow the P.I. to devote more time to these tasks and to support a Co-I whose expertise in modelling limb darkening is needed in developing the second order models.

D. SUMMARY BIBLIOGRAPHY:

Dunbar, R.S. and Tedesco, E.F. (1986). Modelling Pluto-Charon mutual eclipse events. I. First-order models. *Astron. J.*, 92, 1201-1209.

Tedesco, E.F., Veeder, G.J., Dunbar, R.S., and Lebofsky, L.A. (1987). IRAS constraints on the sizes of Pluto and Charon. *Nature*, in press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Imaging of Comets

PERFORMING ORGANIZATION

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

INVESTIGATOR'S NAME

C. M. Telesco

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Brief Statement on Strategy of Investigation:

Using the MSFC Bolometer Infrared Array Camera, comets will be observed from ground-based infrared observatories in the wavelength region 10 μm to 30 μm. Photometric images will be generated from the reduced data to provide a basis for detailed analysis and interpretation.

b. Progress and Accomplishments of Prior Year:

Using the MSFC Infrared Array Camera at the NASA Infrared Telescope Facility, we made the first thermal-IR (10.8 μm) detection of Comet Wilson (September 6, 1986) and 10.8 μm images of Wilson on several successive days in March 1987. The images cover an area of several arc-minutes. This data set is being analyzed to determine properties of the dust distribution including both the quantity and character of the grains. Together with our previously obtained thermal-IR images of Comets Giacobini-Zinner (GZ) and Halley, these data provide a wholly unique perspective on the structure of the inner dust coma.

Detailed analysis of our extensive GZ and Halley observations has continued. The GZ image and the pre- and post-perihelion Halley images were presented at the Heidelberg, Germany Halley Conference in October 1986, and both bodies of data and associated analyses have been published or accepted for publication in refereed journals. A strong effort is continuing to make our images available to the scientific and lay community even before formal publication.

A proposal for observation of Comet Encke at 10-30 μm using the NASA-IRTF was submitted for the observing period August 1987. A determined laboratory effort is continuing to improve the performance of the bolometer array camera through the replacement of crucial optical components, addition of spectral filters, and detailed assessment of the detectors themselves.

c. What Will Be Accomplished This Year:

As part of a methodical study of infrared emission from comets, ground-based observations at major infrared observatories, primarily at the IRTF, will be continued. Typically there will be four comets per year within the sensitivity range of the MSFC Infrared Camera. The next comet selected for observations is Comet Encke.

d. Summary Bibliography:

"Thermal-Infrared and Visual Imaging of Comet Giacobini-Zinner," C. M. Telesco et al., Ap. J. (Lett.), 310, L61 (1986).

"Comet Wilson," R. Decher et al., IAU Circ. 4258 (1986).

"Thermal IR Imaging of Comet Halley," H. Campins et al., Proc. Heidelberg Conference (1986).

"Albedo Maps of Comets P/Giacobinni-Zinner and P/Halley," H. B. Hammel et al., ibid.

"Thermal IR Imaging of Halley," H. Campins et al., Astron. Astrophys., in press, 1987.

"Albedo Maps of Halley and GZ," H. B. Hammel et al., ibid.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Optical and Infrared Imaging

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

R. J. Terrile, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. OBJECTIVES: The purpose of this investigation is to obtain and analyze high spatial resolution CCD coronagraphic images of extra-solar planetary systems and infrared images of the outer planets. These data will provide information on the distribution of planetary and proto-planetary material around the nearby stars leading to a better understanding of the origin and evolution of planetary systems. Imaging within our solar system will provide information on the current cloud configurations on the outer planets, search for new objects around Uranus and Neptune, provide atmospheric rotation periods in support of Voyager, and search for material around asteroids in support of the Galileo project. Infrared imaging of Jupiter will also provide continuity between the Voyager and Galileo projects.

B. ACCOMPLISHMENTS: Over the last year this program acquired multispectral images of a circumstellar disk of orbiting material around the nearby star β Pictoris. This material is believed to be associated with the formation of planets and provides a first look at a planetary system much younger than our own. A coronagraphic search for other proto-planetary systems is also underway. Coronagraphic imaging provided the first clear images and a determination of the geometric albedo of the rings of Uranus and albedo limits for the ring arcs around Neptune. NASA IRTF infrared images of Jupiter and Saturn are providing information on the relative heights and cloud top temperatures of atmospheric features.

C. PROPOSED RESEARCH: A survey of the nearby stars will be continued in order to provide information on the probability of circumstellar material around stars as a function of spectral class and to understand the morphology of young planetary systems. Further imaging of the Beta Pictoris system will also be done in order to obtain spectro-photometric and polarization data on the disk and to image the disk closer to the central star. Coronagraphic imaging of Uranus and Neptune will continue in order to refine the atmospheric rotation rotation period of Neptune as a function of latitude and to spectroscopically image the ring systems of the outer planets. Infrared imaging of Jupiter and Saturn will also be used to continue an analysis of the atmospheric structure and to support the Galileo project by continued monitoring of the Jovian cloud heights.

D. SUMMARY BIBLIOGRAPHY: 2 papers and 6 abstracts published.

PUBLICATIONS

Terrile, R.J. (1986). "Direct Detection of Extra-Solar Planetary Systems from the Ground and Space." Aerospace America, in press.

Porco, C.C., Cuzzi, J.N., Ockert, M.E. and Terrile, R.J. (1987). "The Color of the Uranus Rings." Icarus, submitted.

MEETING AND SYMPOSIA PAPERS ABSTRACTS

Baines, K.H., Terrile, R.J., Wenkert, D. and Smith, B.A. (1986). "Spatial Variability of Aerosols in the Atmosphere of Neptune." Bull. Amer. Astron. Soc., 18, in press.

Terrile, R.J. and Smith, B.A. (1986). "Coronagraphic Searches for Neptune Ring Material." Bull. Amer. Astron. Soc., 18, in press.

Baines, K.H., Bergstralh, J.T., Terrile, R.J., Wenkert, D., Neff, J., Smith, B.A. and Smith, W.H. (1987). "Aerosol and Gas Distributions in the Troposhere of Neptune: Constraints from 'Visible' Broadband Imagery and High-Resolution Spectrophotometry." Bull. Amer. Astron. Soc., in press.

Bergstralh, J.T., Baines, K.H., Terrile, R.J., Wenkert, D., Neff, J., and Smith, B.A. (1987). "Aerosols in the Stratosphere of Neptune: Constraints from Near-IR Broadband Imagery and UV, Blue and Near-IR Spectrophotometry." Bull. Amer. Astron. Soc., in press.

Ftaclas, C., Siebert, E.T. and Terrile, R.J. (1987). "The Circumstellar Imaging Telescope - Direct Detection of Extra-Solar Planets." Bull. Amer. Astron. Soc., in press.

Terrile, R.J. (1987). "Direct Imaging of Extra-Solar Planetary Systems with a Low Scattered Light Telescope." IAU Colloquium 99, Balaton, Hungary.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Fabry-Perot Spectroscopy-Jovian Sulfur Nebula

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

J. T. Trauger, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Application of high spectral resolution, earth based Fabry-Perot spectroscopy to the study of planetary atmospheres, for which current topics are outer planet HD and H2 spectra (atmospheric structure, D/H ratio), Mars CO2, CO, O2, and H2O spectra (atmospheric photochemistry), Venus H2O and HDO (was Venus wet ?), associated laboratory spectroscopy (especially H2 overtone bands, HDO). Monochromatic CCD imaging photometry of the Jovian nebula, with images taken in rapid sequence among the diagnostic spectral lines of ionized sulfur species, providing self supporting snapshots of the Jupiter/Io plasma conditions (spatially resolved electron and ion densities and temperatures), covering the post-Voyager period from 1981 and leading up to the Galileo tour in the early 1990s. High spectral resolution Fabry-Perot/CCD imaging of comets (OI, CI, and H2O+ velocity maps and spatial distributions), and Io's charge exchanged neutral jet (direct probe of Io atmospheric structure).

b. Development of database analysis software to support microVAX - optical disk data archive for F-P/CCD images and planetary spectra. MicroVAX - Raster Technologies image processing hardware integrated. Jovian nebula images database (1980-1986) compiled. Analysis of simultaneous ground based and IUE observations of Jovian nebula (1981-1985) initiated with T. Skinner. Analysis of Doppler resolved image sequences (data cubes) of Io sodium neutrals to isolate diverse collision processes near Io, a sensitive probe of the physical interaction of the nebula and the neutral atmosphere of Io. Radiative transfer programs for outer planet spectral line formation integrated on microVAX, with J.T. Bergstralh. Comet Halley [OI], [CI], and H2O+ image analysis initiated with S.R. Federman.

c. Analysis of existing data and development of data reduction techniques will continue. New observations focusing on the plasma interactions with the Io atmosphere will be carried out. Preparations will be made for Mars photochemistry observations, with D. Crisp. Laboratory spectroscopy of H2 overtone bands at high spectral resolution will be carried out, and data analysis initiated, with M.E. Mickelson. Completion of several papers (outer planet HD/H2, outer planet H2 profiles, Io atmosphere collision processes, Jovian nebula) scheduled this year.

d. J.T. Trauger and J.T. Bergstralh (1986). "Analysis of the (4-0) and (3-0) hydrogen quadrupole line profiles in the atmospheres of Neptune and Uranus," B.A.A.S. 18, 765.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Hypervelocity Intact Capture Technology

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

P. Tsou, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy:

Hypervelocity intact capture technology is developed for a comet coma sample return instrument in the micron to millimeter size particles at impact velocities of 8 to 15 km/s. The collecting process must be gentle so as to leave the samples unaltered as much as possible. Space Station Cosmic Dust Collection Experiment provides an ideal test bed for intact capture technology while capturing Earth encountering cosmic dusts.

The approach will be to employ both theoretical modeling and laboratory simulations. Theoretical analysis will aid in understanding the hypervelocity capture process and guide experiment design. Hypervelocity accelerators will be used to produce impacts of comet-like particles. Experimental collectors will be flown on Space Station and Shuttle for evaluation in a realistic space environment. Laboratory analyses using chemical, isotopic, and mineralogical techniques will be used to assess and guide the development.

b. Progress and Accomplishments During the Prior F/Y:

Joint Code EL and EB funding provided for a systematic data base for intact capture and permitted the formulation of a preliminary model for hypervelocity intact capture.

c. Accomplishments Anticipated for This Period:

1. An expanded working model of the hypervelocity intact capture covering mass balance, energy distribution, temperature profile, and shock pressure will be formulated.

2. Identify and formulate new capture media to capture comet-like projectiles intact at speeds higher than 4 km/s towards 7 to 8 km/s, and

3. Perform laboratory simulation experiments to develop new capture media to determine scaling laws in media density, microstructure, and material properties and in projectile size, shape, and compositions.

d. Summary Bibliography (most recent papers):

Tsou, P., D. Brownlee, & A. Albee, "Hypervelocity Intact Capture in Multiple-Layer Films", 18th LPSC, pp. 903-904, 1987.

Tsou, P., D. Brownlee, & A. Albee, "Comet Coma Sample Return", ESA SP-250 Vol. III, pp. 237-241, 1986.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Astronomy and Supporting Laboratory Research

PERFORMING ORGANIZATION

Ames Research Center
Moffett Field, CA 94035

INVESTIGATOR'S NAME

Valero, F. P. J., Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

13. Description

a. Strategy: To obtain from laboratory measurements the molecular parameters needed to interpret observations of planetary and cometary spectra, and to develop the analytical and computational techniques to interpret the observed spectra in terms of planetary atmospheres including solids and cometary ices. The gas phase molecular parameters measured include the intensities and half-widths of vib-rotational lines, total intensities of absorption bands, temperature dependencies, and absorption and pressure parameters in random-band models of absorption bands. Computation of line shapes of H2 quadrupole lines from quantum mechanical first principles for comparison with laboratory data and use in modeling of planetary atmospheres. The solid phase measurements include band profile and quantitative intensity measurements and dependence on composition as well as thermal and photolytic processing which mimic the particular astrophysical environments.

b. Progress: Work on GeH4, PH3, CH3D have continued. Several papers have been published (see list under publications). A new experimental set-up using a Ca doped germanium detector together with the very high resolution BOMEM FTIR spectrometer and special absorption cells have been developed. Modeling of the geometric albedo spectrum of Titan is under development using CH4 absorption coefficients determined in our laboratory. The 0.4 to 1.0 um region has been done, at the present time work is in progress in the near IR (1.1 to 2.6 um).

c. Plans: The spectra of PH3 will be obtained and work on CH3D and GeH4 will be extended. The modeling effort on Titan's Spectrum will continue in the 1.1 to 2.6 um region.

d. Publications: "Determination of Ao for CH3D from Perturbation-Allowed Transitions" C. Chcakerian et al. Jour. Mol. Spect. 117, 355, 1986. "Absolute Line Strengths of PH3 Gas near 5/um" R.W. Lovejoy et al. 109, 246 (1985). "Intensity Measurements of Individual Lines and Manifolds in the Spectrum of the 5 Micron Fundamental Band of Germane" L.P. Giver and C. Chackerian, in preparation. Line lists on tapes: (include E, Nu and S). Nu3 Band CH3D atmos. Geisa, AFGL-Several CO2 bands AFGL.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Physical Properties of Asteroids

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

G. J. Veeder, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. **OBJECTIVE:** We propose to study the physical properties of asteroids by telescopic observations and laboratory and theoretical work. Spectrophotometry from 0.3 to 1.1μm and 1.2, 1.6, 2.2, and 3.5 μm photometry allow spectral/compositional classification of asteroids. Infrared measurements at 1.2, 1.6, and 2.2 μm provide a relatively rapid and accurate method for the classification of the minor planets and are very important in comparing asteroids with meteorites. We have proven this technique in the main belt during the past years and now propose to employ it in a compositional survey of Apollo-Amor-Aten, and other unusual asteroids observed by IRAS. Radiometry at 4.8, 10 and 20μm will provide diameters and albedos.

B. **PROGRESS:** During FY-87 we obtained JHKMN and/or Q data on 50 asteroids at the NASA Infrared Telescope Facility on Mauna Kea. These include 10 planet-crossing objects, two of which are the first known *M* class near-Earth asteroids. We have constructed thermal models for Deimos and the nucleus of P/Arend-Rigaux. We have initiated a new program to follow-up IRAS asteroids at the IRTF.

C. **PROPOSED WORK:** In FY'88 we propose to: (1) continue the 1.2, 1.65 and 2.2 survey photometry of planet-crossing asteroids; (2) follow-up selected asteroids observed by IRAS at additional wavelengths as needed (*e.g.*, visual photometry, thermal radiometry and CVF or CGAS spectrophotometry); (3) infrared observations, including 10- and 20-μm photometry, of any bright Apollo-Amor-Aten asteroids discovered by the Helin search; (4) compare reflectance data from 1.2 to 2.2 μm for asteroids to meteorites and compare radiometry with thermal models to examine evidence for (and against) the presence of metallic regoliths on *M* class asteroids; and (5) compare thermal models for small rocky asteroids with observations of comet nuclei.

D. **SUMMARY BIBLIOGRAPHY:** Veeder, G.J., *et al.* (1987). The nucleus of comet P/Arend-Rigaux. ***Astron. J.***, in press; Veeder, G.J., *et al.* (1987). Radiometry of Deimos. ***Astron. J.***, submitted. Tedesco, E.F., and Gradie, J. (1987). Discovery of *M* Class Objects Among the Near-Earth Asteroid Population. ***Astron. J.***, 93, 738.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Compositional Studies of Primitive Asteroids

PERFORMING ORGANIZATION

NASA Johnson Space Center
Code SN3
Houston, TX 77058

INVESTIGATOR'S NAME

Faith Vilas

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Narrowband CCD reflectance spectra of 34 outer-belt and main-belt primitive asteroids were obtained in 1982 - 1985. Spectra of 22 asteroids were divided into four groups based upon four discrete slopes among the spectra. The discrete slope changes suggest that these asteroids are the remnants of a compositional gradation in the outer solar system, selectively retained in location when other material was ejected from the early solar system. Additional CCD spectra and spectra in the 3.0 - 4.0 micron range are proposed, with the objective of studying the compositional components of the primitive asteroid surfaces. This information should provide new understanding of the relationship between these asteroids and comets or other primitive solar system bodies.

b) New proposal.

c) Planned accomplishments: (1) Obtaining new narrowband CCD reflectance spectra of outer-belt and main-belt primitive asteroids in the 0.5 - 1.0 micron spectral range. (2) Combining these new spectra with existing spectra of 34 primitive asteroids and examining them for weak absorption features seen near 0.6 - 0.7 microns in terrestrial clay silicates and carbonaceous chondrites attributed to iron oxides. If a statistically significant sample of spectra is obtained, the hypothesis proposing selectively-retained remnants of an early solar system gradation in composition of asteroids will be tested. (3) Obtaining spectra in the 3.0 - 4.0 micron spectral range to search for a C - H stretch absorption seen in terrestrial organic polymers.

d) Bibliography:

Vilas, F., and B. A. Smith (1985). "Reflectance Spectrophotometry (0.5 - 1.0 m) of Outer-Belt Asteroids: Inplications for Primitive, Organic Solar System Material." Icarus, 64, 503-516.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Passive Microwave Remote Sensing of Asteroids Using the VLA

PERFORMING ORGANIZATION

Geophysics Branch (Code 622)
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME

William J. Webster. Jr., Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Precise flux density measurements made with the Very Large Array (VLA) of the National Radio Astronomy Observatory will be used to define the microwave continuum spectra of asteroids. These spectra will be inverted in order to estimate the near-surface bulk properties (radii, roughness, composition) independent of previous optical or infrared spectroscopy.

b. The results on 15 Eunomia and 704 Interamnia have been published. The paper in 1 Ceres is about to be submitted to Icarus. A paper on the simple models of asteroid radio spectra has been submitted to the Publications of the Astronomical Society of the Pacific. Preliminary analyses of 2 Pallas, 4 Vesta and 10 Hygeia have been completed.

c. High spatial resolution 2 cm observations of 1 Ceres and 2 Pallas will be attempted. Previous data have been unsuitable for highest resolution mapping due to adverse weather conditions. 20 cm data will be acquired for 2 Pallas and 4 Vesta. If the new cooled 3.3 mm receiver is available for the 12 m Kitt Peak antenna, we will attempt observations of 15 Eunomia and 704 Interamnia. The results for 2 Pallas, 4 Vesta and 10 Hygeia will be submitted for publication.

d. Summary Bibliography:

Webster, W.J., Jr., Hobbs, R.W. and Lowman, P.D., Jr. (1984), Detection of λ=2 cm Emission from Minor Planet 15 Eunomia, Icarus, 60, 538.

Webster. W.J., Jr., P.D. Lowman, Jr., and R.W. Hobbs (1985), On Interpreting the Microwave Continuum Spectra of Asteroids, presented at the 164th meeting of the American Astronomical Society.

Webster, W.J., Jr., Lowman, P.D., Jr. and Hobbs, R.W., (1985), On the Microwave Spectrum of the Larger Asteroids, presented at 166th Meeting of the American Astronomical Society.

Webster, W.J., Jr., Hobbs, R.W. and Lowman, P.D., Jr. (1987), Detection of λ=2 cm Emission from Minor Planet 704 Interamnia, Icarus, 69, 29.

Webster, W.J., Jr. (1987, On the Simple Models for the Interpretation of Centimeter-Wavelength Radio Observations of Asteroids, submitted to PASP.

Webster, W.J., Jr., Johnston, K.J., Hobbs, R.W., Wade, C.M., Lowman, P.D., Jr., and Seidlelman, P.K. (1987), The microwave spectrum of Asteroid 1 Ceres, to be submitted to Icarus.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Origin of Asteroids and Small Bodies

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

J. G. Williams, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Objectives: Comets and asteroids are observed with the Palomar 1.5m telescope using a CCD array. The goal is observations of astrometric quality (the reduction to positions is separately funded) and the priorities are comets plus minor planets which are planet crossers, Trojans, Hildas, have high inclinations, or otherwise have unusual orbits. The stress is on recoveries of comets and asteroids seen at previous oppositions and follow up on newly discovered objects. Surveys and new discoveries are not being attempted. The modest amount of available dark time is used for faint objects, while brighter objects can be followed in the more plentiful light time. Since asteroids are usually discovered near perihelion when bright, the next several opportunities for recovery are normally fainter. Thus big telescopes complement discoveries by smaller instruments.

b) Progress: During the past year six periodic comets were recovered. They were P/Holmes (1986f), P/Forbes (1986g), P/Schwassmann-Wachmann 2 (1986h), P/Klemola (1987i), P/Reinmuth 2 (1987l), and P/Brooks 2 (1987m). A follow up observation of the newly-discovered Nishikawa-Takamizawa-Tago (1987c) appeared on an IAU card as did the report of a lack of detection of the previously bright P/Lovas 2 (1986p) implying precipitous fading (it was later recorded as a faint, diffuse patch). Follow up observations of the newly-discovered Apollo asteroid 1986WA were also reported on the cards. The faint Amor type asteroid 1984KD (with q=1.009 au) was recovered giving a second recorded opposition and assuring that it will never be lost. A variety of additional interesting comets and asteroids were also recorded.

c) Proposed Research: The CCD observing program will be continued on the 1.5m Palomar telescope for the recovery of faint comets and minor planets. The priorities will emphasize first opposition follow up and second opposition recovery. Comets and unusual asteroids will be given priority. This is not a survey program.

d) Publications: The comet recoveries and other time-critical observations were presented on IAU cards 4225, 4229, 4231, 4290, 4291, 4345, 4349, 4369, and 4372.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Spectroscopy of Comets (NAGW-547)

PERFORMING ORGANIZATION

Arizona State University

INVESTIGATOR'S NAME

S. Wyckoff
P. A. Wehinger

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

Spectroscopic observations were obtained of Halley and other comets during the past year using telescopes of large aperture (≥ 4 meters) and state-of-the-art detectors. The data were analyzed to determine ion velocities, neutral molecule scalelengths, ion and neutral molecule production rates, isotopic abundance ratios and to discover new molecular features. Specific results for 1986 have been:

1) Discovery of moderately strong molecular ion features in the plasma tail of comet Halley.

2) Discovery of a new excitation mechanism for molecules in a comet, namely red-shifted uv fluorescence of CO_2^+ features observed in the 4000-5000 A region.

3) Determination of the CO^+/H_2O^+ abundance ratio in comets Giacobini-Zinner and Halley.

4) Measurement of the $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios in comet Halley from both the CN and C_2 bands.

5) Determination of scalelengths and production rates for CH, NH_2 and C_2 from long-slit CCD spectra of comet Halley at the time of the GIOTTO encounter. We calculate a NH_3 abundance smaller than determined from the in situ mass spectrometers.

6) Measurement of H_2O^+ acceleration in the plasma tail of comet Halley from echelle spectra.

7) Gas and dust production rates of comet Halley monitored over a heliocentric distance range of 5 AU.

8) A Monte Carlo model has been developed which determines scalelengths and production rates more accurately than either the vectorial or Haser models.

Objectives for the coming year will be to:

1) Complete the reduction of the long-slit CCD data of comet Halley obtained in 1985 and 1986 using the NOAO IRAF reduction software.

2) Continue development of the Monte Carlo model for interpreting the data.

3) Secure additional spectroscopic observations of Halley and other comets using telescopes of large aperture. We intend to concentrate our observational efforts on comet Tempel 2, in support of the CRAF mission objectives.

Relevant Publications

S. Wyckoff
P. Wehinger
NAGW-547

"Comet Halley Report: May 1986", S. Wyckoff and P. Wehinger, Mercury 15, (1986).

"Detection of CN Emission in Comet P/Halley (1982i)", S. Wyckoff, P. Wehinger and M. J. S. Belton, in Asteroids, Comets and Meteors 2, Uppsala Symposium, 487-490 (1986).

"Kitt Peak Spectroscopy of P/Halley, H. Spinrad, P. Wehinger, S. Wyckoff and M. J. S. Belton, in Asteroids, Comets and Meteors, Uppsala Symposium, 491-495 (1986).

"Molecular Ions in Spectra of P/Halley", S. Wyckoff, P. Wehinger, H. Spinrad and M. J. S. Belton, 20th ESLAB Symposium on the Exploration of Halley's Comet, p. 56 (1986).

"Radial Profiles for Gas and Dust in the Coma of the Comet P/Halley", B. L. Lutz, R. M. Wagner and S. Wyckoff, 20th ESLAB Symposium on the Exploration of Halley's Comet, p. 153 (1986).

"Spectra of the Plasma Tail of Comet Halley", S. Wyckoff, P. Wehinger, H. Spinrad and M. J. S. Belton, COSPAR Symposium on Comet Halley, Toulouse, (1986).

"Spectra of the Plasma Tail of Comet P/Giacobini-Zinner", S. Wyckoff, P. Wehinger, S. Konno, H. Spinrad and M. J. S. Belton, 20th ESLAB Symposium on the Exploration of Halley's Comet, p. 56 (1986).

"The Behavior of P/Halley at Large Heliocentric Distance in the Light of the Giotto/Vega Results", M. J. S. Belton, P. Wehinger, H. Spinrad and S. Wyckoff, 20th ESLAB Symposium on the Exploration of Halley's Comet, p. 249 (1986).

"The Swan C_2 (0-0) Band in Comet Halley",P. Wehinger, B. A. Peterson, S. Wyckoff, E. Lindholm E. F. van Dishoeck, R. Gradel and J. H. Black, 20th ESLAB Symposium on the Exploration of Halley's Comet, p. 58 (1986).

"The Violet CN (0-0) Band R-Branch Spectrum of Comet Halley", P. Wehinger, B. A. Peterson, S. Wyckoff, E. Lindholm and M. Festou, 20th ESLAB Symposium on the Exploration of Halley's Comet, p. 57 (1986).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND TECHNOLOGY RESUME

TITLE

Cometary Dynamics

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

D. K. Yeomans, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a.) In order to provide observers with accurate ephemerides of comets and asteroids, up-to-date astrometric positions must be used to improve the existing orbits. For active comets, nongravitational forces must be taken into account; these forces are assumed due to the rocket-like effect of outgassing cometary ices and are used to characterize the volatility and rotation properties of icy cometary nuclei. In an effort to improve the ephemeris accuracies, the benefits of a new data type (radar data) are being investigated.

b.) The orbit and ephemeris of periodic comet Tempel 2 were updated allowing its successful recovery in Jan. 1987 at a heliocentric distance of 4.3 AU. Accurate orbit and ephemerides were computed for asteroids 46 Hestia, 1627 Ivar, 1982 DB, 878 Mildred, and 1986 JK - the latter object's improved orbit allowed its being successfully observed with the Goldstone radar facility. Accurate ephemerides of approximately 16 comets and asteroids were distributed to an international group of observers and an error analysis was completed that clearly demonstrated the strong sensitivity of future ephemeris accuracies to the inclusion of a few radar observations (Doppler and range) in the orbital solutions.

c.) A capability for actually processing radar data in the comet and asteroid orbit determination software will be initiated and existing radar data for close Earth-approaching asteroids will be used for program checkout. Ephemerides and orbits for various comets and asteroids will be provided to interested observers during the 1987-88 observing season.

d.) Yeomans, D.K., Ostro, S.J. and Chodas, P.W. "Radar Astrometry of Earth-Approaching asteroids", Astronomical Journal, June 1987 (in press)

Yeomans, D.K. "Physical Interpretations from the Motions of Comets Halley and Giacobini-Zinner", in Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, ESA SP-250 (Dec. 1986), pp. 419-425.

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16. Abstract

This is a compilation of abstracts of reports from Principal Investigators funded through NASA's Planetary Astronomy Program, Office of Space Science and Applications. The purpose is to provide a document which succinctly summarizes work conducted in this program for 1986. Each report contains a brief statement on the strategy of investigation and lists significant accomplishments within the area of the author's funded grant or contract, plans for future work, and publications.

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